Hospital Filtration Systems: Airborne Contaminant Control

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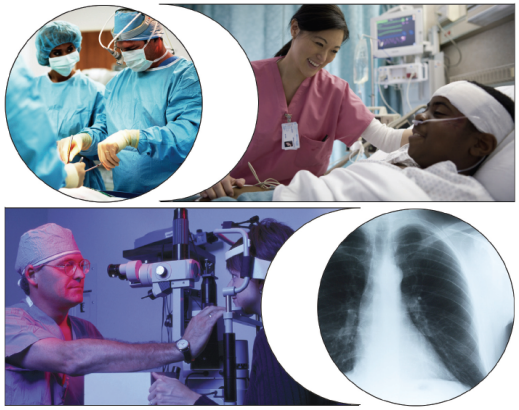
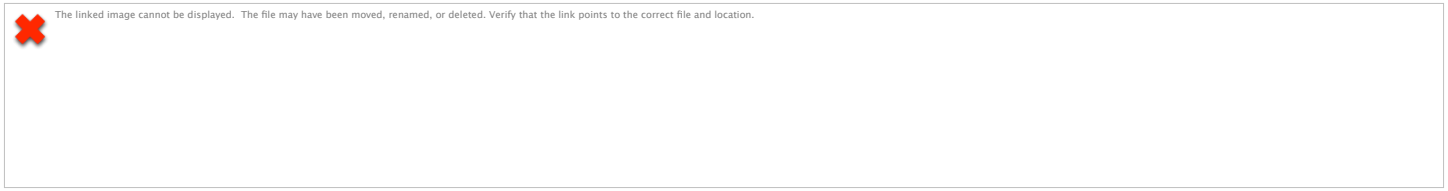
ASHRAE Singapore

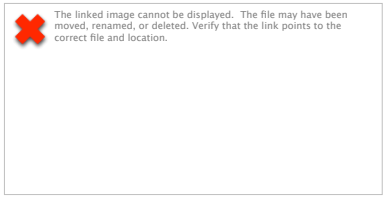
Shaping Tomorrow's Built Environment Today

OBJECTIVES

1. Outline specific sections of ASHRAE Standard 62.1 as it applies to Healthcare Facility filtration.
2. Identify various AHU design strategies that can comply with ASHRAE 90.1 as it pertains to Hospital filtration.
3. Review the predominant filtration technologies that can be incorporated into central station AHU's to minimize Particulate, Chemical and Biological contaminants.
4. Evaluate methods of reducing life-cycle cost without sacrificing adequate air purification.
5. Explore air cleaning methods that compliment dilution and can serve as a means of controlling airborne infection, and contaminants from entering into the Healthcare Environment.







- **Control of Airflow and Particle Dispersion in Hospital rooms by CFD and Ventilation Effectiveness Analysis**
- **Nosocomial Infection Related to Environments in Large Facilities**
- **H1N1 Update and Airborne Infectious Diseases in Schools and Child Care Centers**
- **SARS, Influenza and Hospital Ventilation**

Filtration Committees

TC 2.3 Gas
TC 2.4 Particulate
TC 2.9 UVGI (Systems / Equipment Ch. 16)
TG HVAC Security (Application Ch. 58)

HEALTHCARE FACILITY DESIGN



Contaminant sources

Agion® / antimicrobial

HEPA filtration

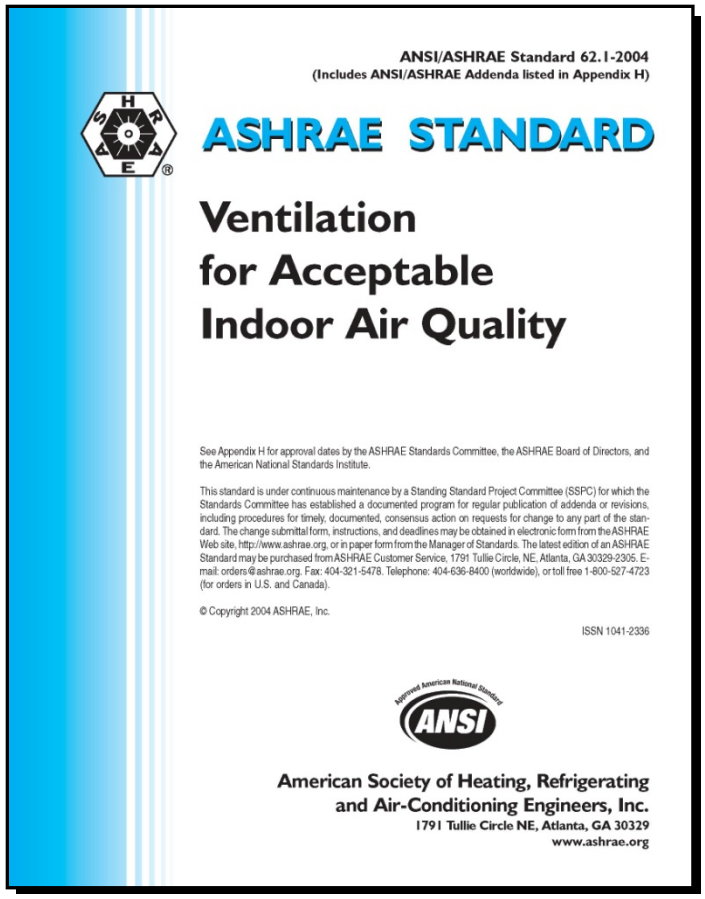
UVGI technology

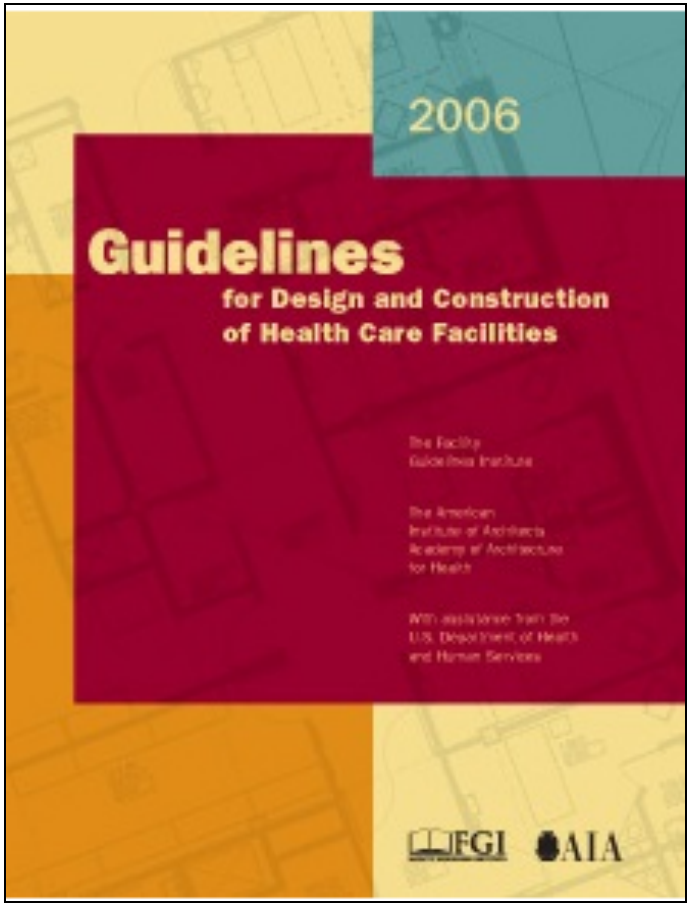
Room pressurization

AHU Construction

Indoor Environmental Quality EQ P1 & EQ 1

- Provide adequate ventilation air

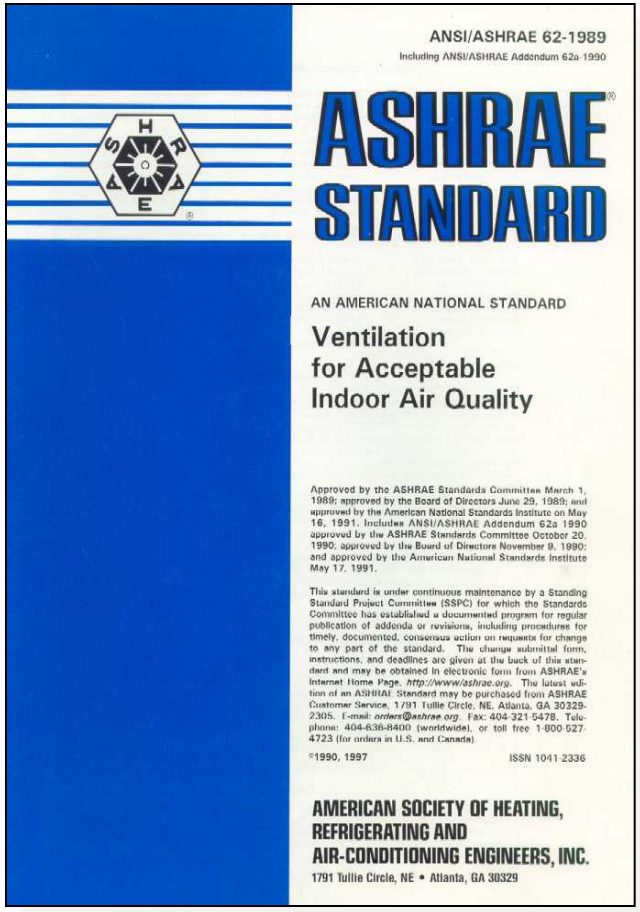




Green Guide for HealthCare (GGHE)

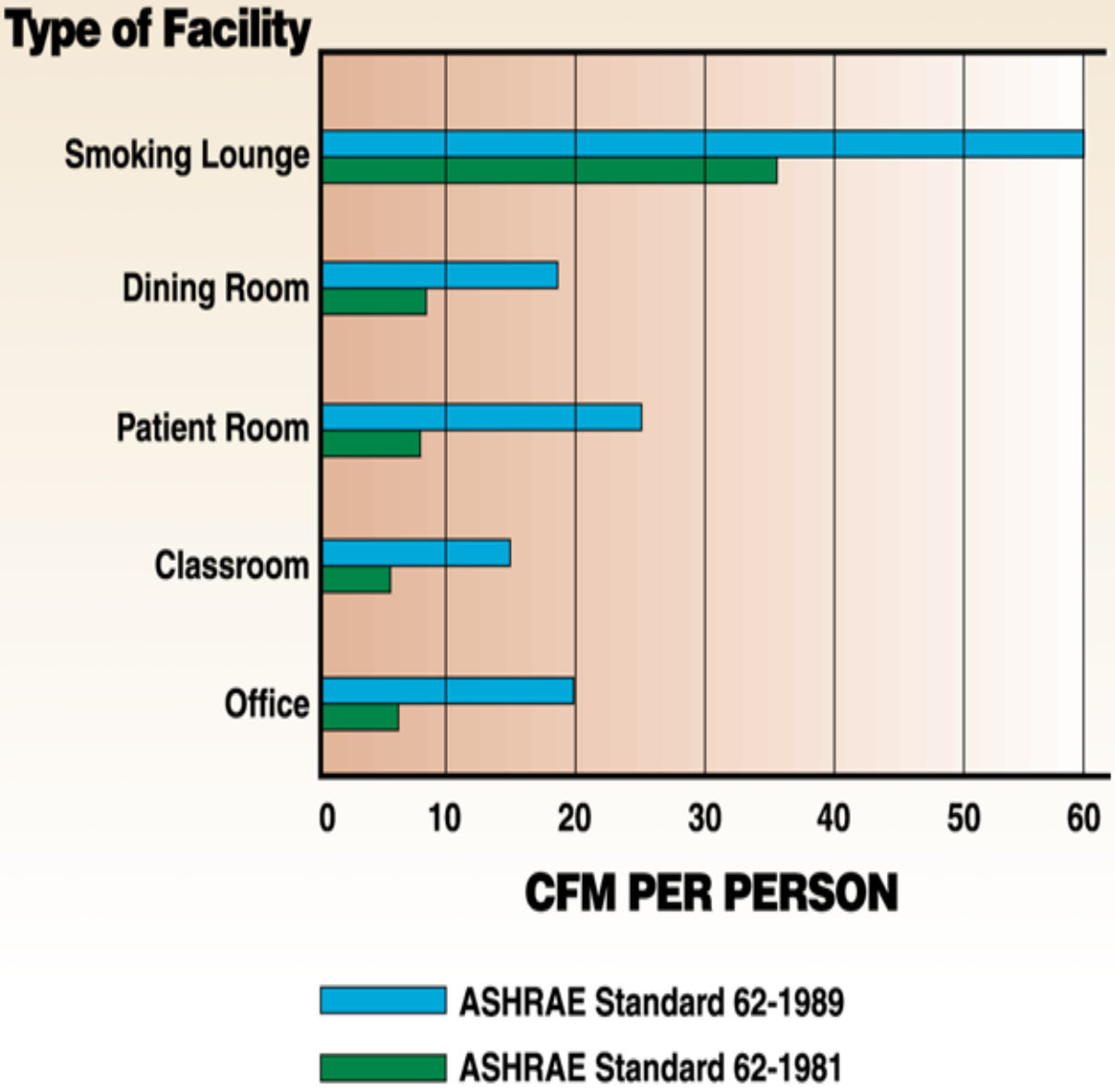


THE OUTDOOR ENVIRONMENT

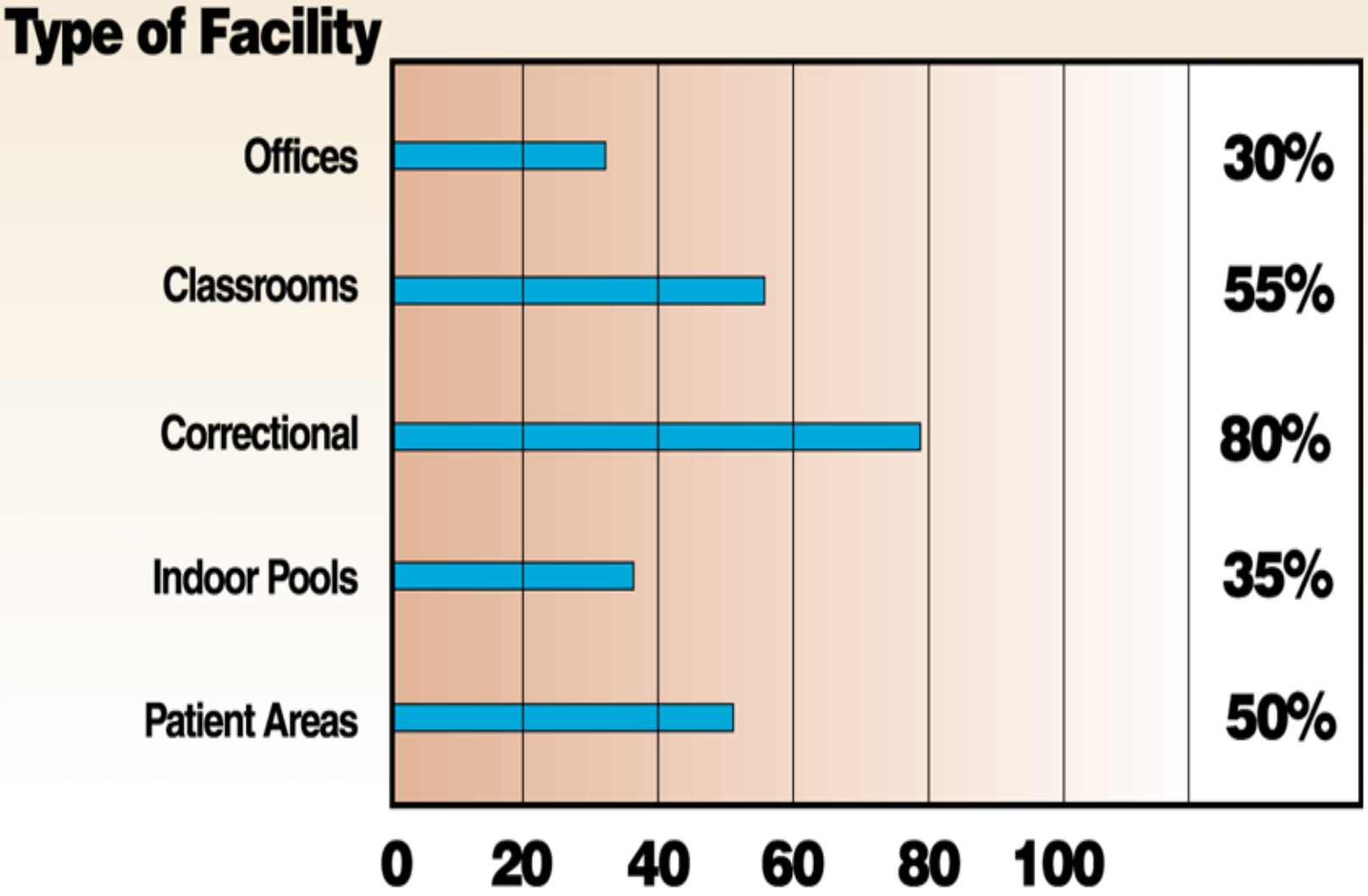


Prescriptive standard which dictates minimum amounts of outdoor air to maintain acceptable indoor air quality within a space.

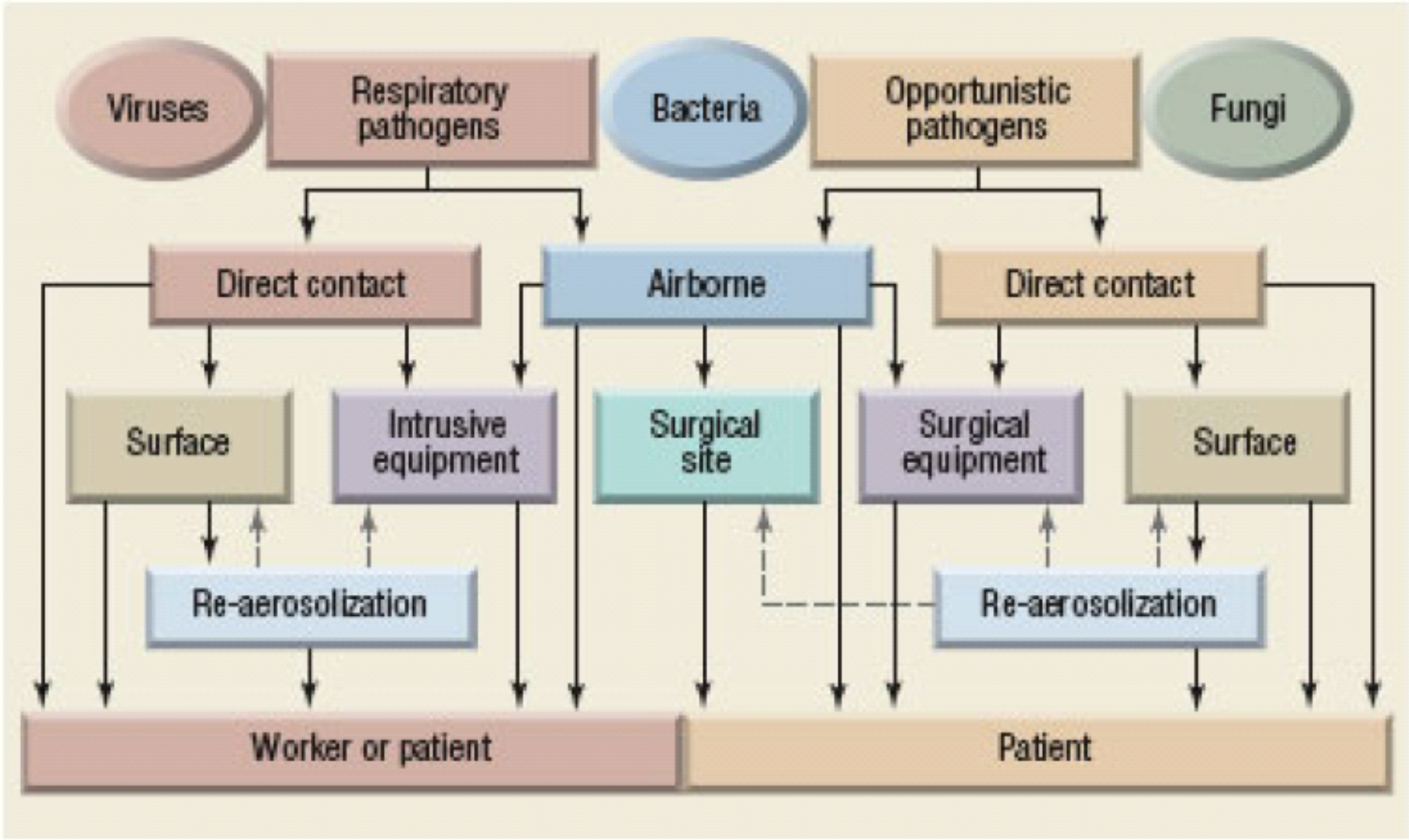
Outside Air


Type of Facility
Smoking Lounge
Dining Room
Patient Room
Classroom
Office
0
10
20
30
40
50
60
CFM PER PERSON
ASHRAE Standard 62-1989
ASHRAE Standard 62-1981

Outdoor Air as a Percentage of Supply Air



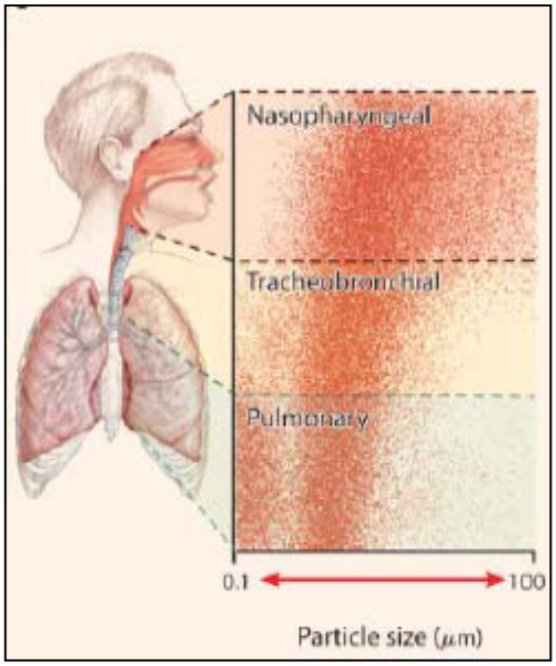
INFECTION PATHS

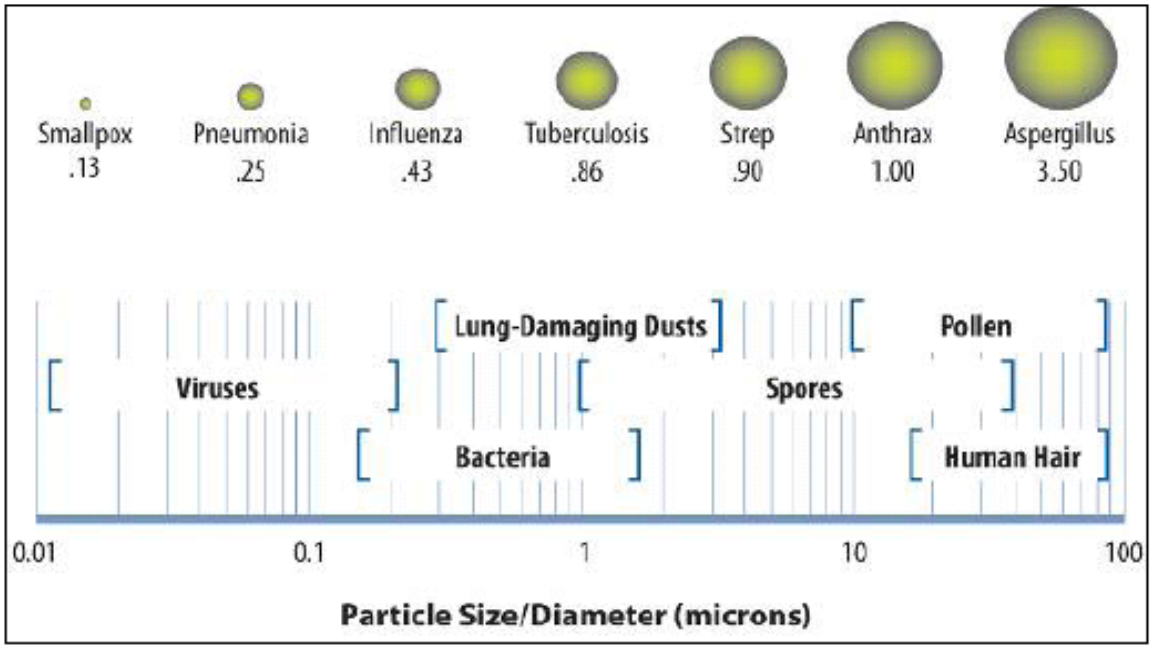


BREATHING ZONE

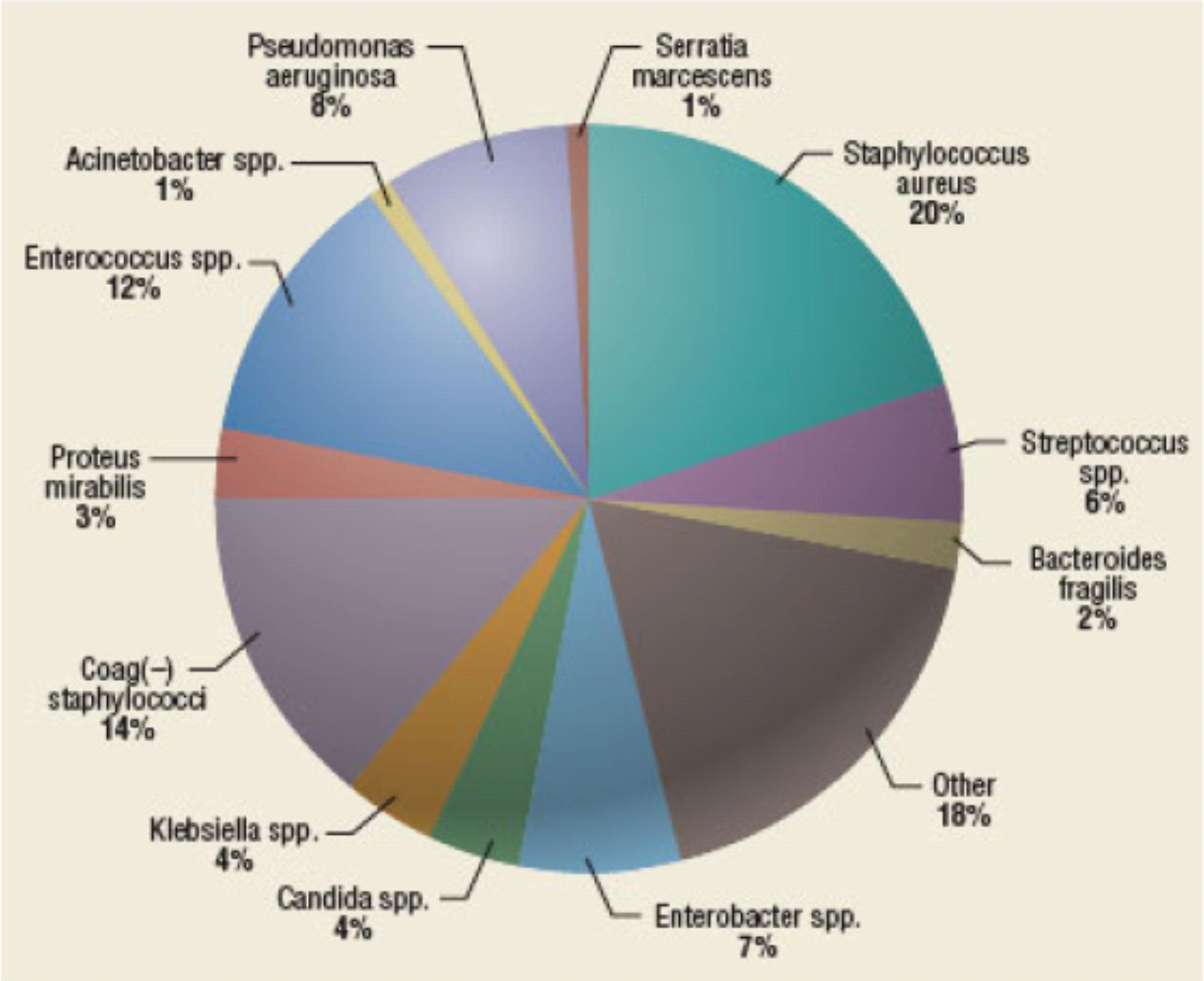
A cubic foot of indoor air contains ~1.5 million particles – 99% of these are smaller than a micron

Small particles, pathogenic or not, are the most damaging as they are carrier deepest into the lungs





NOSOCOMIAL INFECTIONS ARE WIDESPREAD



Some Are Prevalently Airborne; Virtually all CAN Be Airborne

INFECTION CONTROL STRATEGY

Contact (Skin)

Ingestion

Airborne Transmission



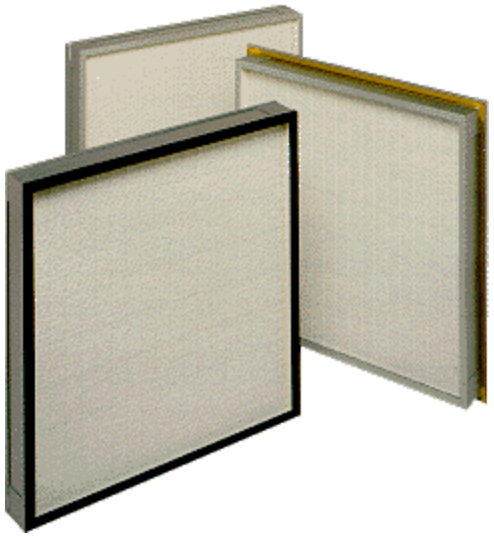
Technology Available:

Particulate Filtration

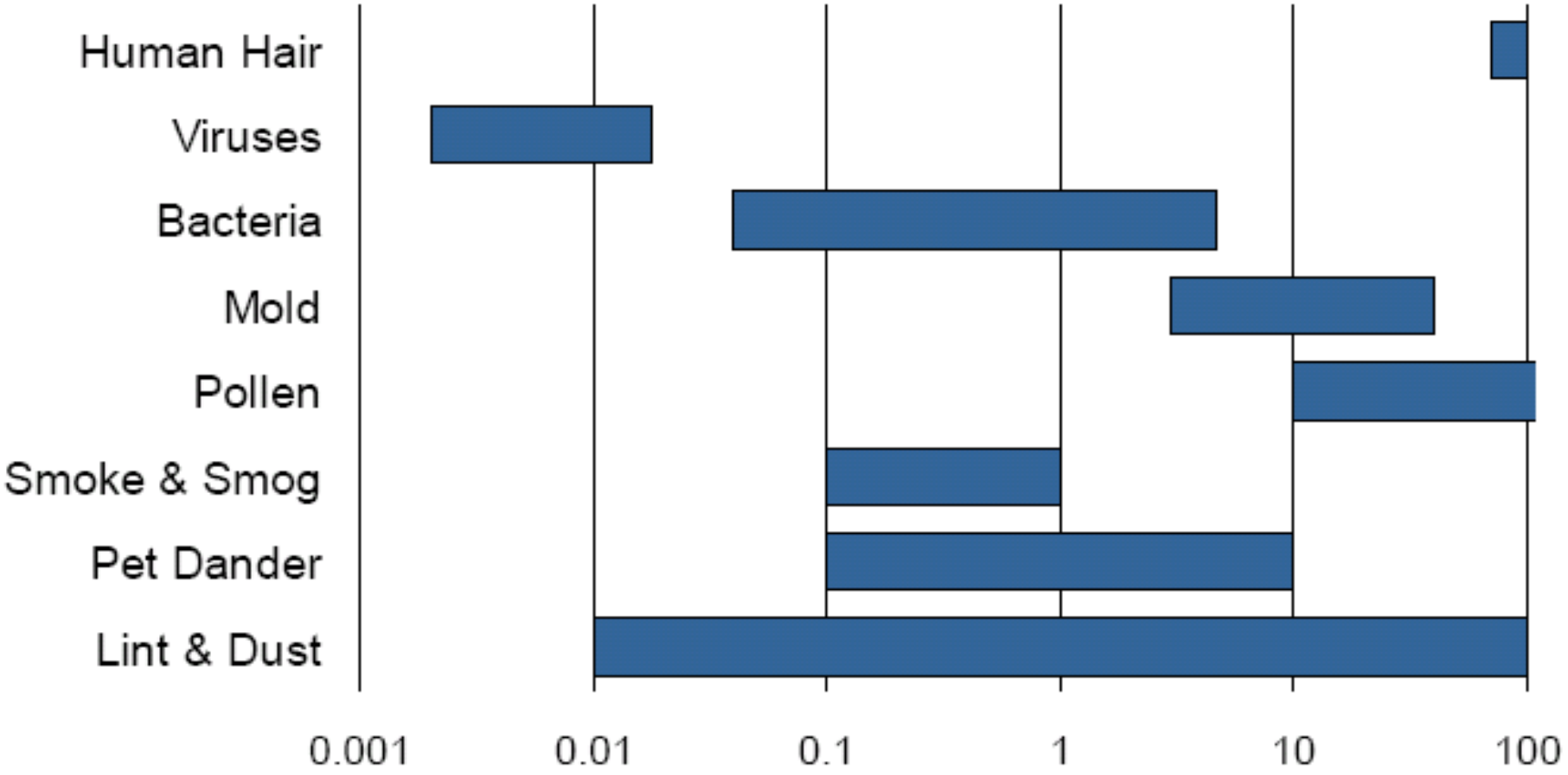
Chemical Filtration

Biological Filtration

Ventilation Design



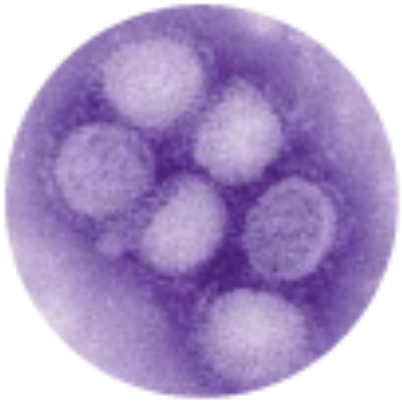
PARTICULATE CONTAMINANTS



Minimum Efficiency Reporting Value	
MERV 5-8	3 to 10 microns
MERV 9-12	1 to 3 microns
MERV 13-16	0.3 to 1 microns

Airborne infection control

H1N1 Best Practices — Best Products — Best Protection



- H1N1 virus is very small — 0.1 microns — HEPA filters are the best choice for increased protection.
- MERV 16 filters are recommended for installations where HEPAs are not applicable.

Airborne transmission, as occurs in tuberculosis and H1N1, is spread through small groups of infectious particles called droplet nuclei. These very small droplet nuclei can be readily disseminated by air currents to susceptible individuals.

AIR CONTAMINANTS

Type	Diameter (μm)	Time
Human Hair	100-150	5 seconds
Skin Flakes	20-40	
Observable Dust in Air	>10	
Common Pollens	15-25	
Mite Allergens	10-20	5 minutes
Common Spores	2-10	
Bacteria	1-5	
Cat Dander	1±0.5	10 hours
Tobacco Smoke	0.1-1	
Metal and Organic Fumes	<0.1-1	
Cell Debris	0.01-1	
Viruses	<0.1	10 days

MERV RATINGS FOR PARTICLE FILTRATION

MERV	Particle Size	Typical Pollutants	Applications	Filter Types
1	>10 µm	Pollen, Dust mites, Sanding dust	Residential, Light commercial	Construction, Throwaway
2				
3				
4				
5	3-10 µm	Dust, Molds, Spores	Commercial, Manufacturing	Pleated, Panel Filters
6				
7				
8				
9	1-3 µm	Legionella, Auto Fumes, Welding Dust	Commercial, Industrial	Bag, Cartridge, Mini-pleat
10				
11				
12				
13	0.1-0.3 µm	Tobacco smoke, Copier toner, Bacteria	Commercial, Medical, Industrial	Bag, Cartridge
14				
15				
16				
17	<0.3 µm	Sea salt, carbon dust, chem-bio, viruses	Clean rooms, Surgery, Isolation	HEPA
18				
19				
20				ULPA



Pleated



Cartridge



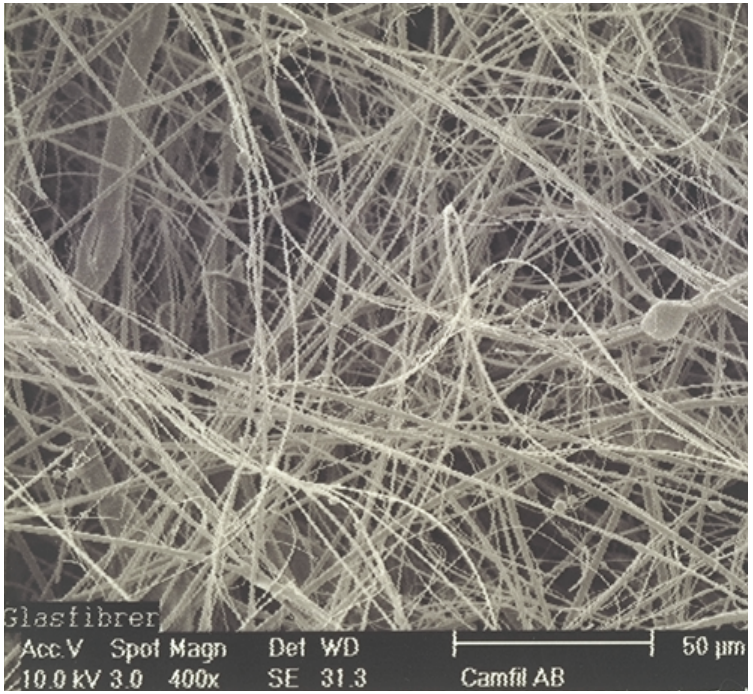
Bag

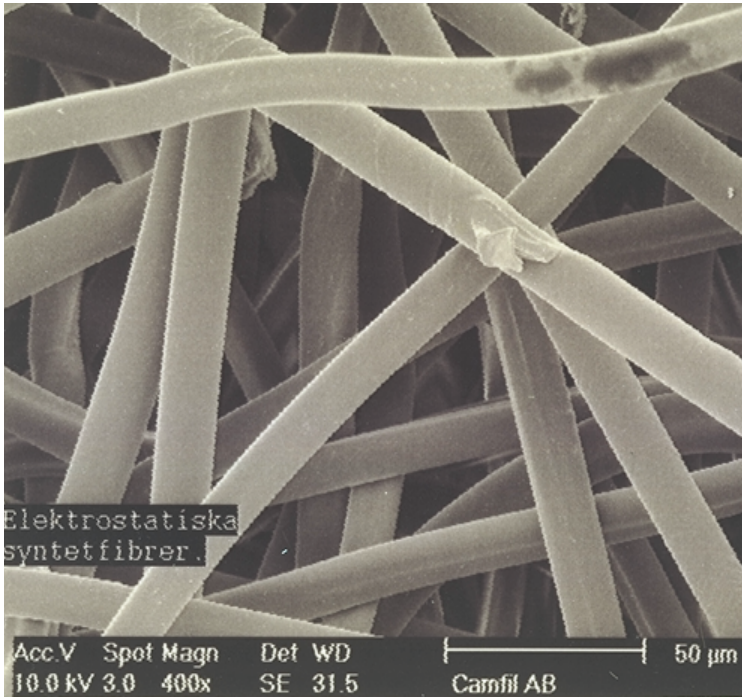
electrostatic charge

ASHRAE 52.2 :

– *“Some fibrous media air filters have electrostatic charges that may be either natural or imposed upon the media during manufacturing.* ***Such filter may demonstrate high efficiency when clean and a drop in efficiency during their actual use cycle.*** *The initial conditioning step of the dust-loading procedure described in this standard may affect the efficiency of the filter but not as much as would be observed in actual service.* ***Therefore, the minimum efficiency during test may be higher than that achieved during actual use.”***

Why fiber diameter matters?





- Glass Fibers
  - Many Fibers
  - Small Diameter
- Synthetic Fibers
  - Fewer Fibers
  - Large Diameter

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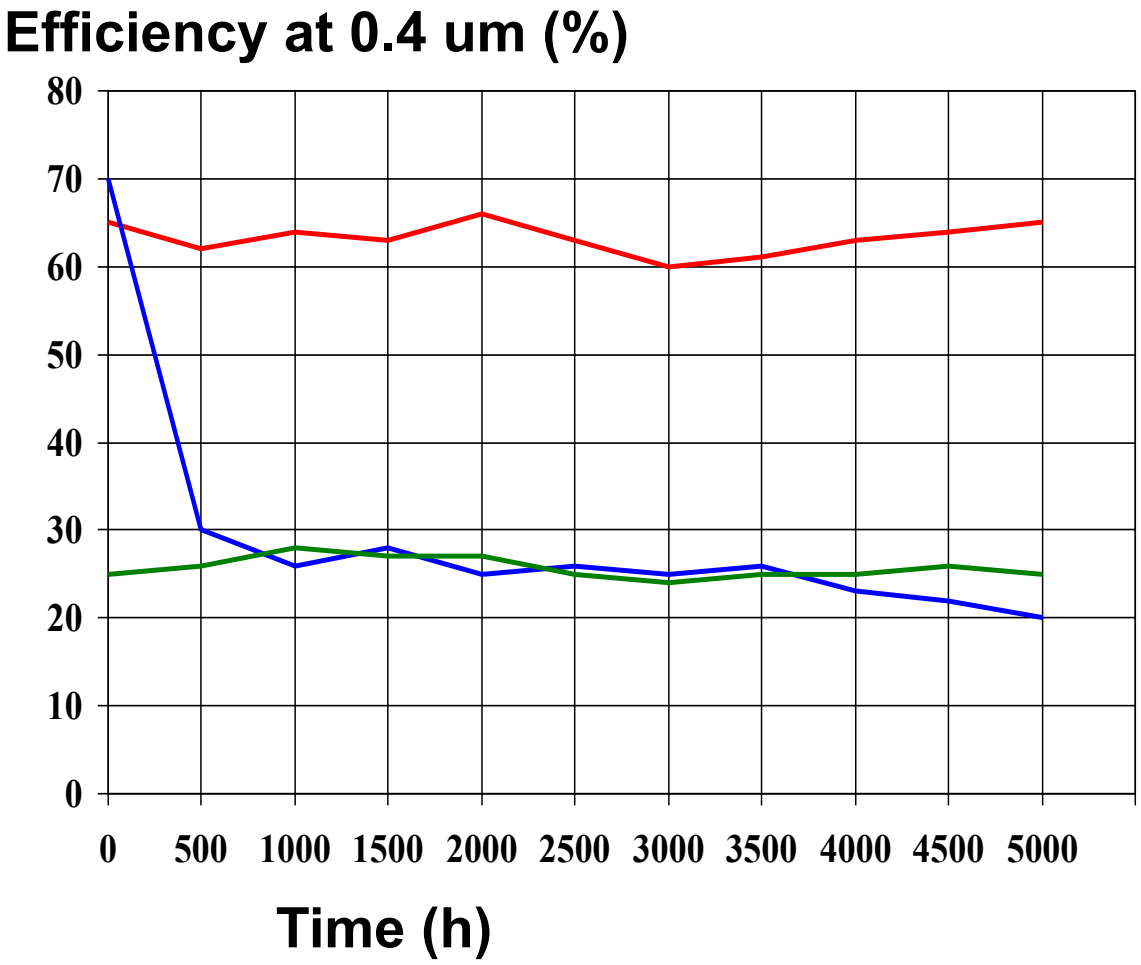
Fine fibre vs. Coarse charged fibre



- MERV 14 Glass media
- MERV 14 Synthetic media
- MERV 11 Glass media

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PARTICULATE FILTER STAGES





HealthCARE MERV

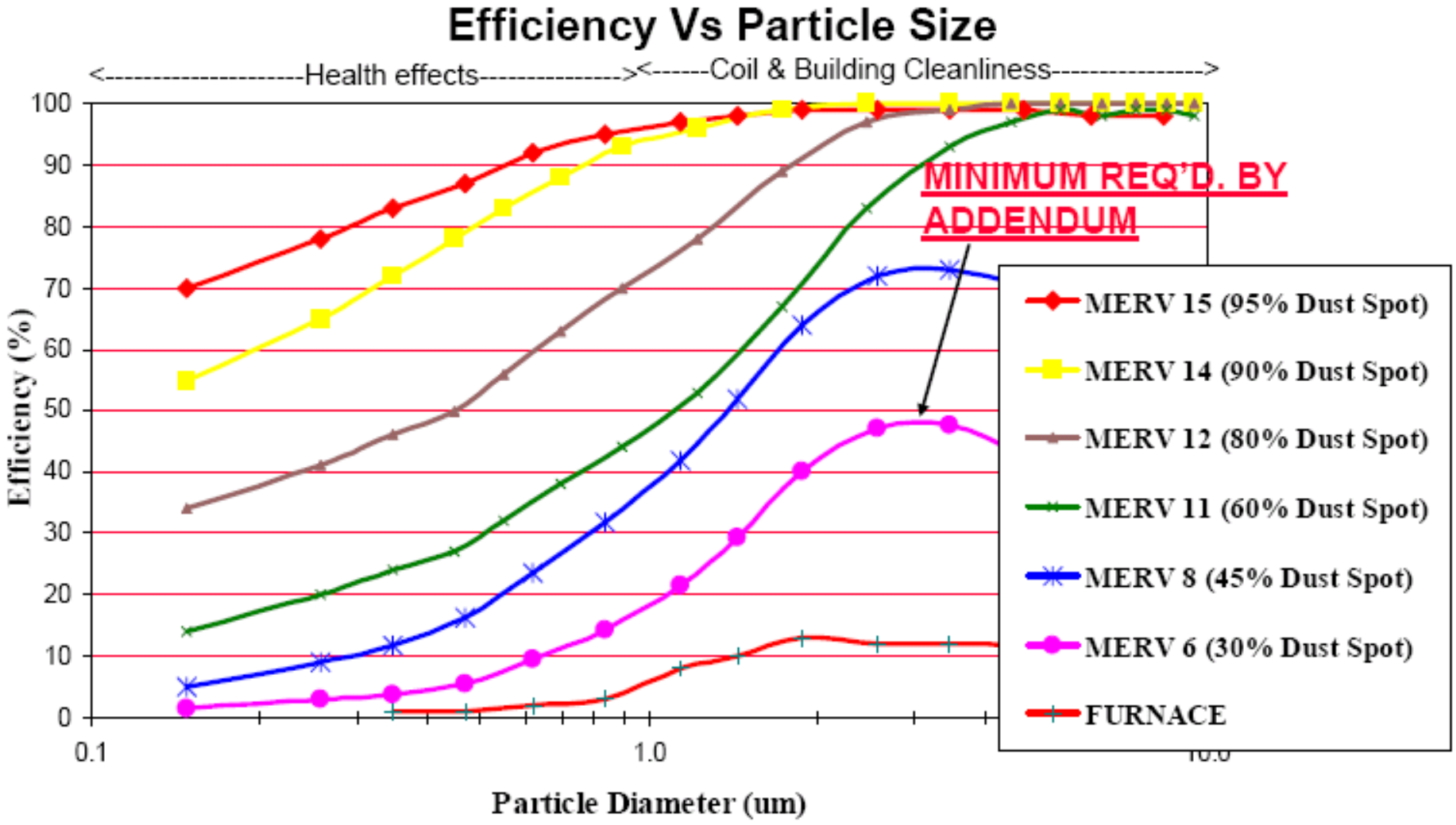
Filter Efficiencies for Central Ventilation and Air Conditioning Systems

Minimum Number of Filter Beds	Area Designation	Filter Efficiencies MERV* Filter Bed No.1	Filter Efficiencies MERV* Filter Bed No.2
General Hospitals and Outpatient Treatment Facilities			
2	Orthopedic Operating Room Bone Marrow Transplant O.R. Organ Transplant O.R.	8	17[b]
2	General Procedure Rooms Delivery Rooms Nurseries Intensive Care Units Patient Care Rooms Treatment Rooms Diagnostic & Related Areas	8	14
1	Laboratories Sterile Storage	13	
1	Food Preparation Areas Laundries Administrative Areas Bulk Storage Soiled Holding Areas	8	
Nursing Homes and Diagnostic Centers			
1	Patient care, treatment, diagnostic, and related areas	15	
1	Food preparation areas and laundries	8	
1	Administrative, bulk storage, and soiled holding areas	6	

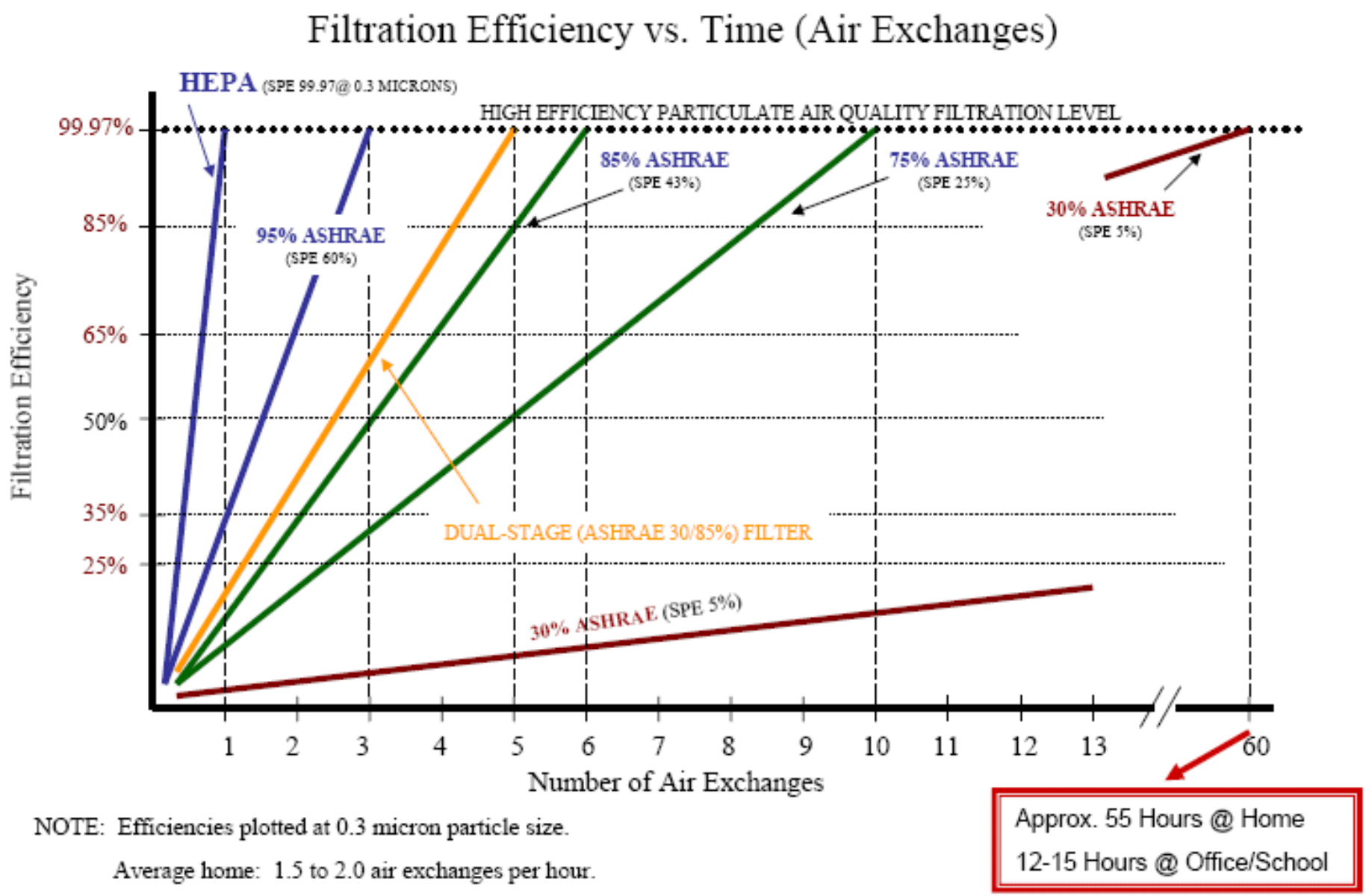
* Minimum Efficiency Reporting Value based on ASHRAE 52.2 [b]HEPA filters at air outlets.

Minimum Filtration

ASHRAE 52.2-1999 and 62-2001



Single vs. Multi-stage Filter Comparison

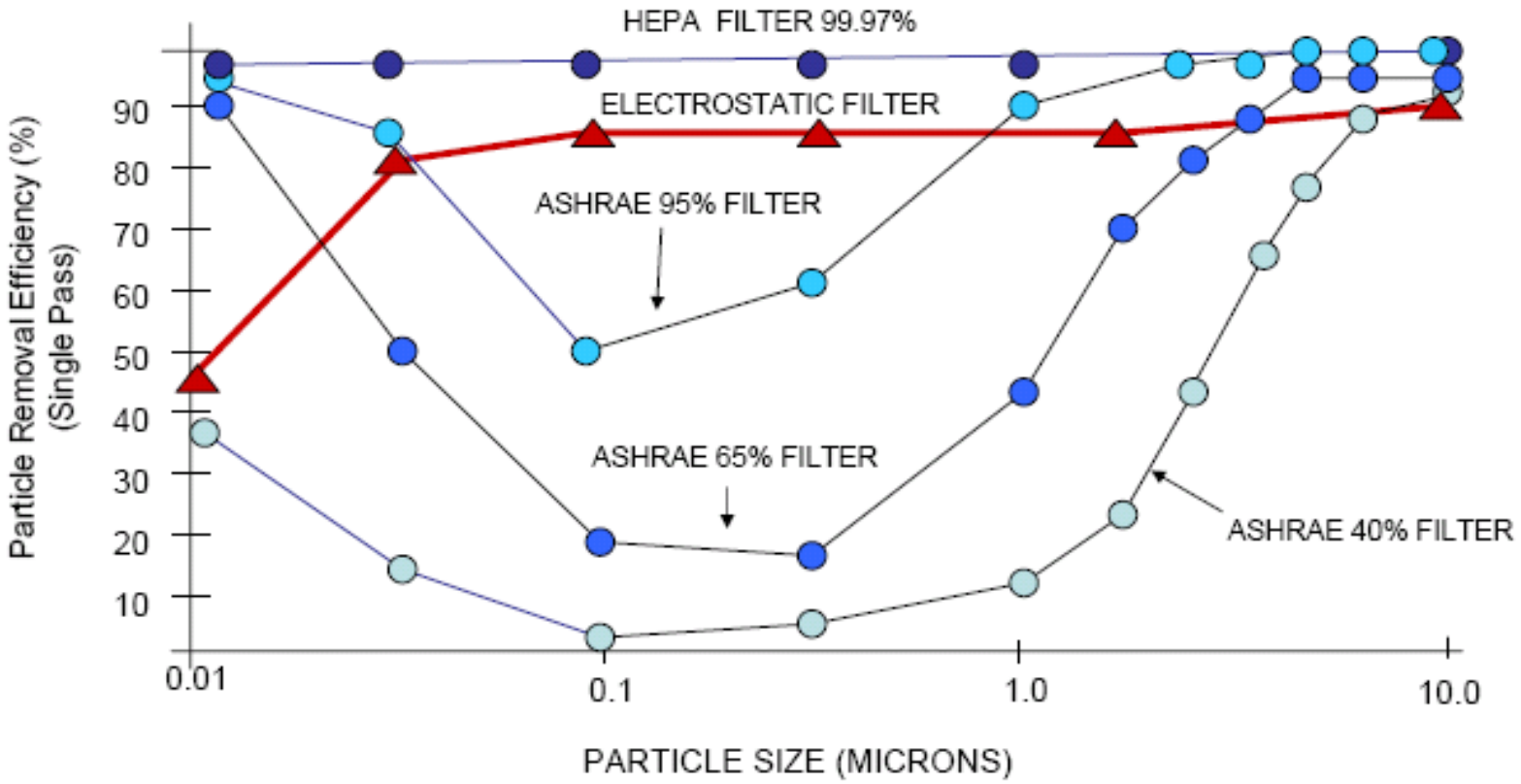


NOTE: Efficiencies plotted at 0.3 micron particle size.

Average home: 1.5 to 2.0 air exchanges per hour.

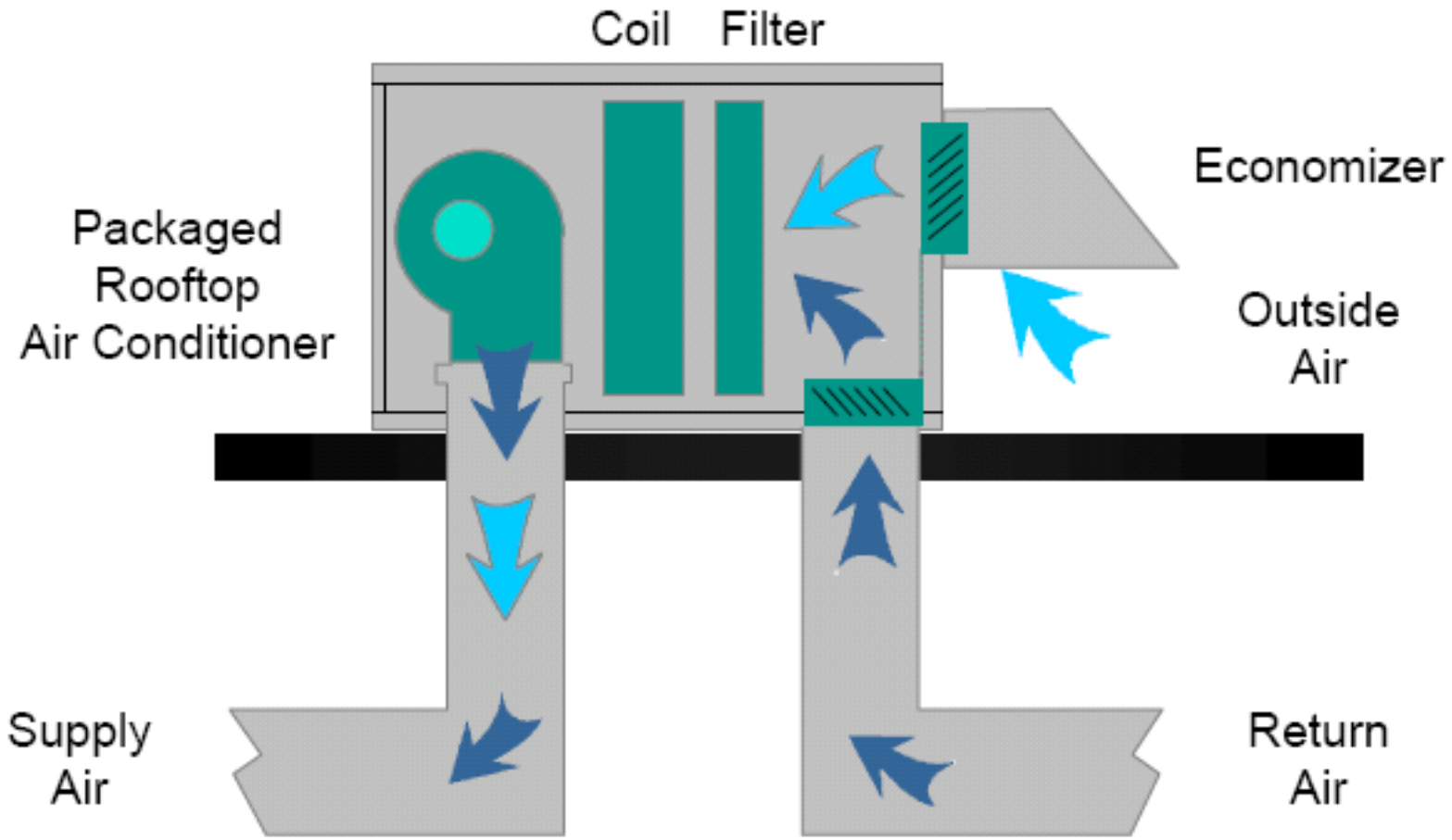
XX% ASHRAE Rating refers to Dust Spot Efficiency of Media

Comparison of Single Pass Efficiency Curves for Filters and Electrostatic Precipitator

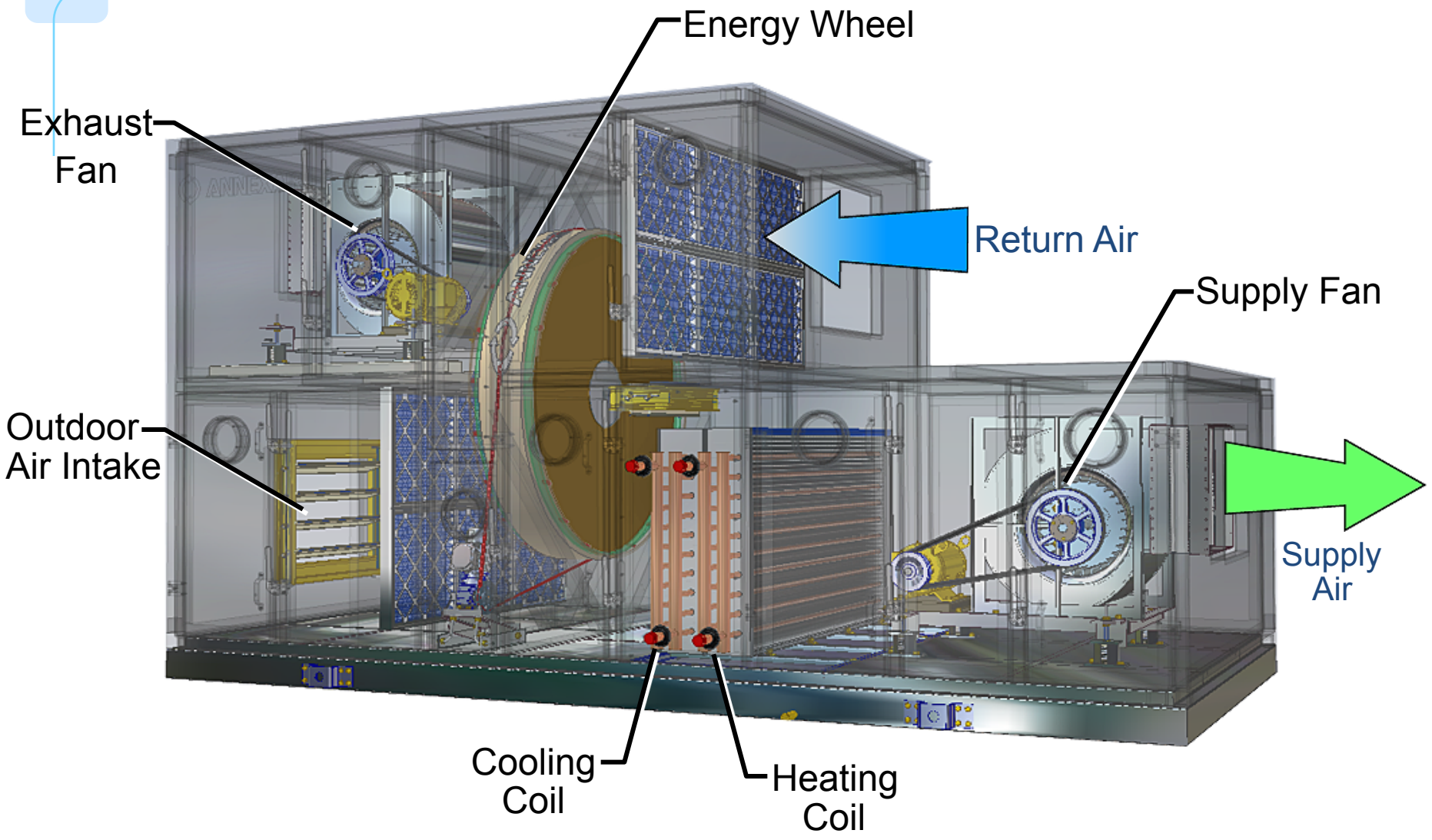


The single pass efficiency of an ASHRAE 30% filter is 5%.

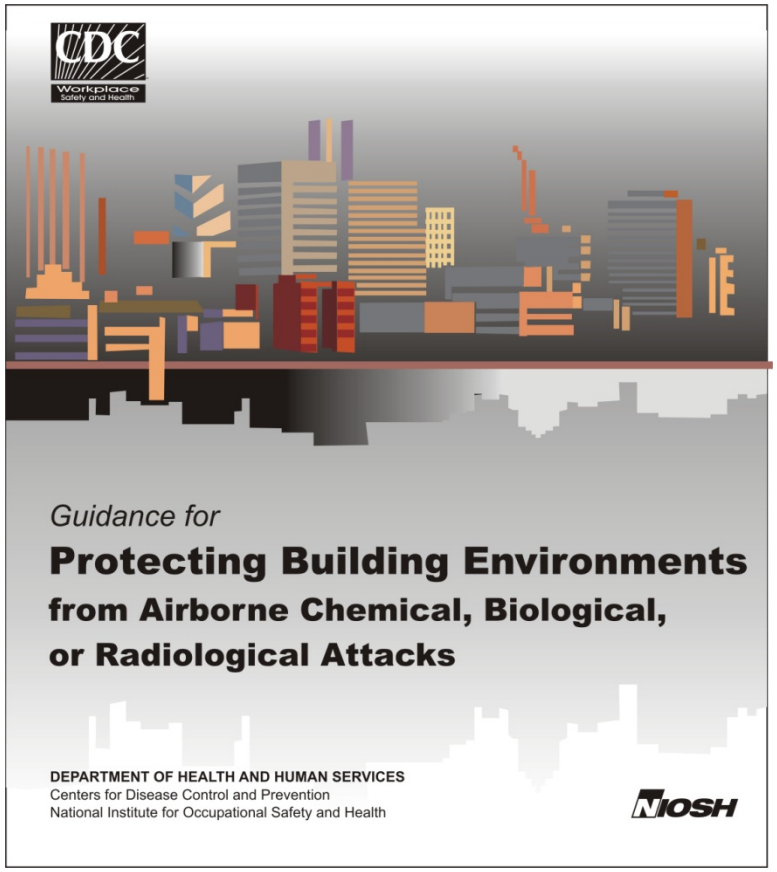
PACKAGED ROOFTOP UNIT

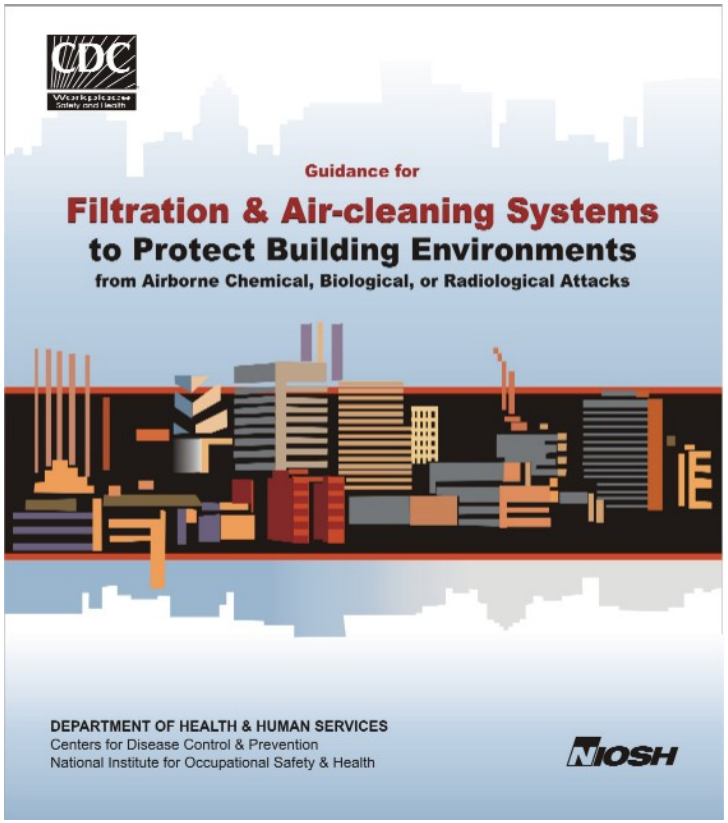


Strategies for Energy Savings

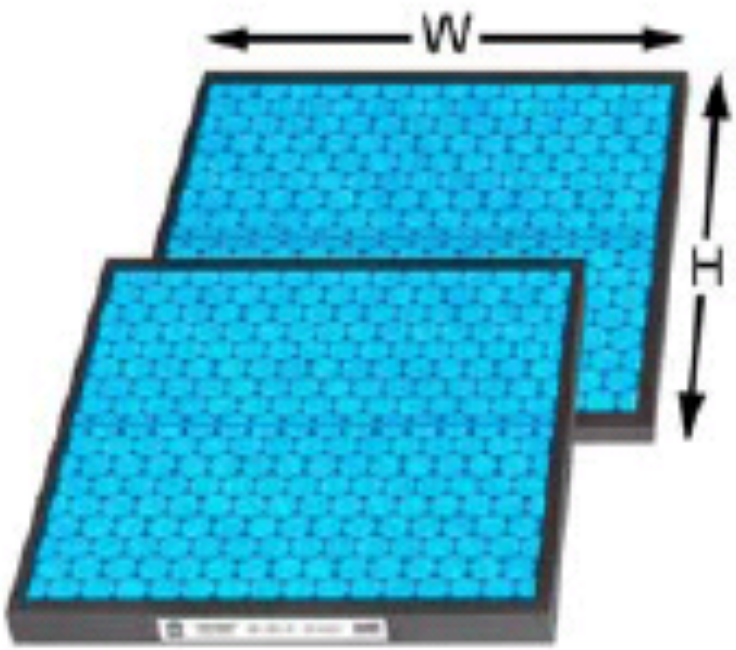


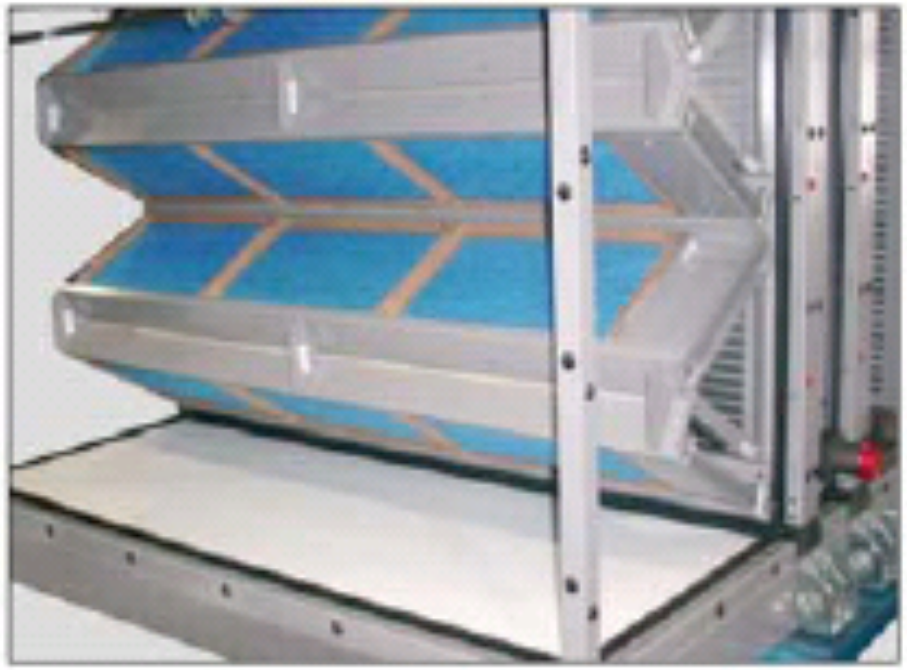
CDC Filtration Document





AHU DESIGN





Capacity(cfm) / area = velocity

Minimum Energy Performance

GGHC requires complying with ASHRAE 90.1 – 2004 (or local code if more stringent*)

Sect. 5.4 & 5.5 Envelope Requirements

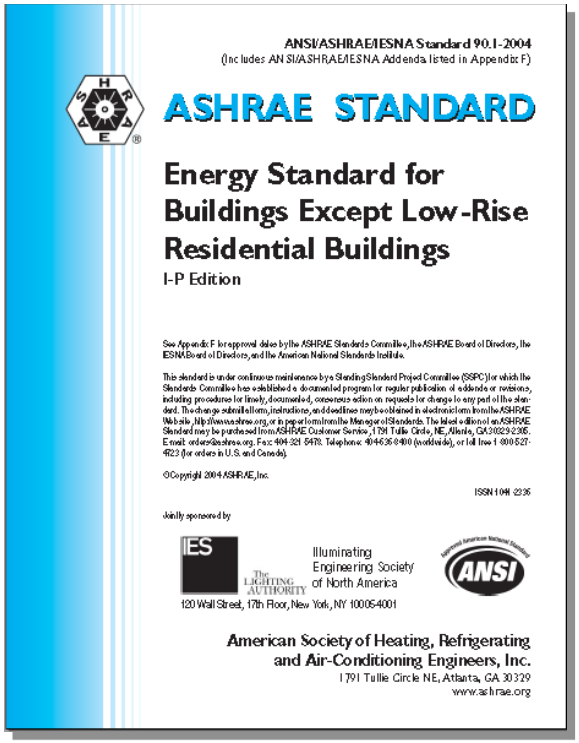
Sect. 6.4 & 6.5 HVAC Equipment

Sect. 7.4 & 7.5 Service Water Heating

Sect. 8.4 Power voltage drop

Sect. 9.4 & 9.5 Lighting control and density

Sect. 10.4 Electric Motors



* See WWW.energycodes.gov/implement/determinations_com.stm

*prescriptive requirements

OPERATING COST

To calculate the operating cost of the filter we can use the following procedure:

The equation for horsepower for a fan is: $hp = \frac{(cfm * P_s)}{6350}$

P_s is the filter static pressure drop as measured by the methods shown previously. The number 6350 is a constant for air. If we take into account normal losses for belt drives, typical motor efficiencies, and typical fan efficiencies, we can arrive at an equation for the kW (kilowatts) required. This kW will be for the fan to move air across a filter whose static pressure drop and cfm is known. This equation works out to be:

$kW = .0002 * cfm * P_s$

We assume a motor efficiency of 90 percent, fan efficiency of 67 percent, and drive losses of 4 percent.

Knowing the hours of operation of the fan, and the cost of electricity in kWH we can easily convert the filter resistance into fan operating cost.

Unfortunately, the filter resistance is constantly changing as the filter becomes dirtier. It is necessary to use a value of pressure drop that is considered representative during the time duration.

Example: Calculate the cost of operating a 30,000 cfm fan with a bag filter section whose static pressure drop including prefilters is measured at 2.2 in. wg. The fan runs 8 hours a day year round. The cost of electricity is $0.08 kWH.

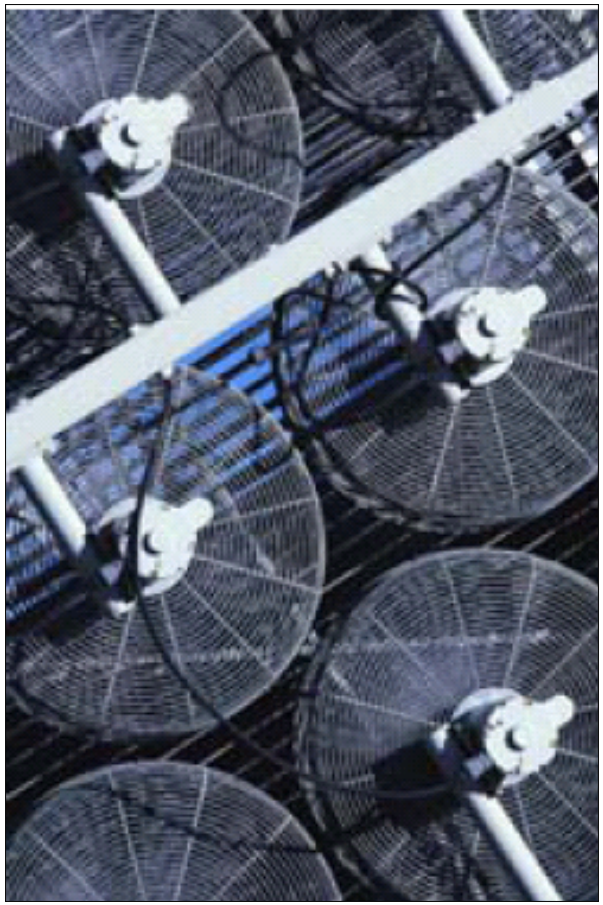
Annual operating cost $= 0.0002 * 30{,}000\ cfm * 2.2\ in.wg * 8\ hrs/day * 365 days/year * \$0.08/kW$

$= \$3{,}083$ per year

HEALTHCARE ENERGY

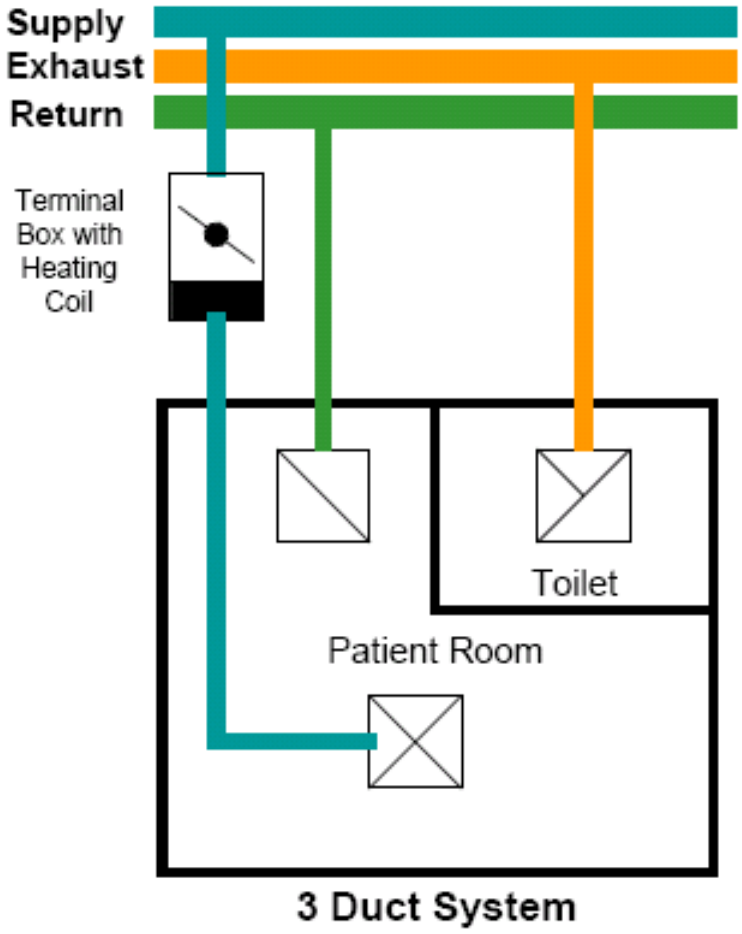
HVAC – An Opportunity for Savings

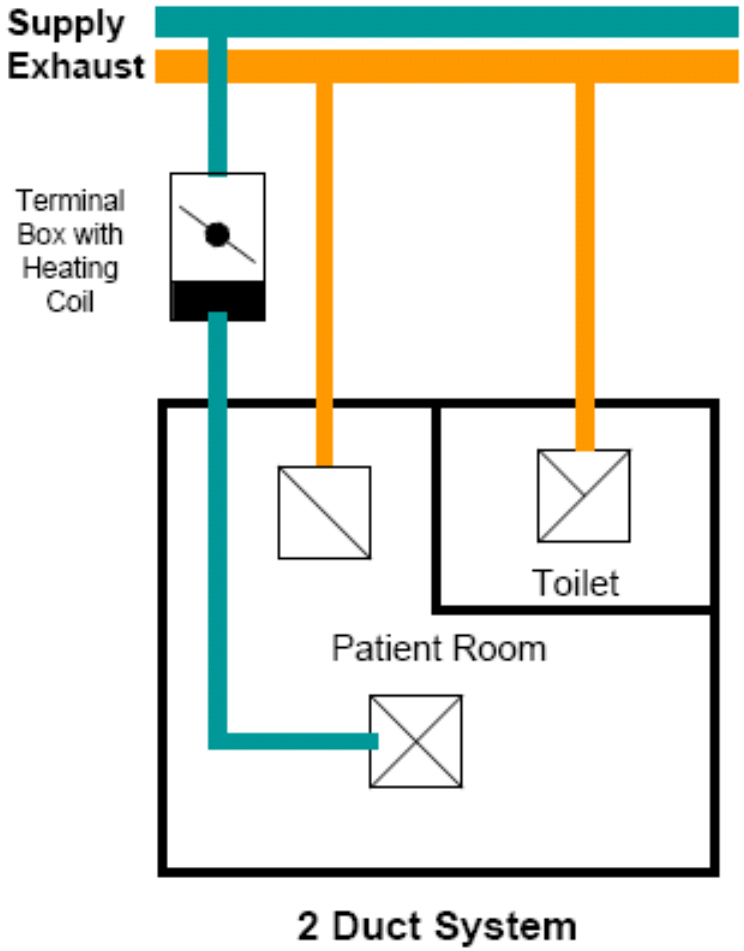
- Fan system is oversized 60%
  - Potential savings 50-85%
- Cooling system
  - Potential savings 15-35%
- Heating System
  - Potential savings 5-35%
- The solution
  - Right size equipment
  - High efficiency components
  - Energy efficient motors
  - Variable speed drives
  - Improved controls
  - Economizer strategies



VENTILATION DESIGN

Recirculated Air or 100% Outdoor Air





ASHRAE HealthCare Guide

	Air Movement Relationship to Adjacent Area	Minimum Air Changes Of Outdoor Air Per Hour	Minimum Total Air Changes Per Hour
Surgery and Critical Care			
Intermediate Care	—	2	6
Gastrointestinal Endoscopy Room	Out	2	6
Endoscopic Instrument Processing Room	In	—	10
Laser Eye Room	Out	3	15
X-ray (Surgical/ Critical Care and Catheterization)	Out	3	15
Ancillary			
Lab Biochemistry	In	—	6
Lab Serology	In	—	6

Table 1: Ventilation requirements for areas affecting patient care in hospital and outpatient facilities.

VENTILATION DESIGN

Displacement Ventilation Patient Rooms

Conditioned air is introduced through a low side wall configuration

Particle movement with displace ventilation moves in very distinct “piston effect” versus completely random particle displacement found in traditional overhead HVAC

4 Air changes per hour with 100% outdoor air versus 6 air changes per hour with recirculated air

INDUSTRY DOCUMENTATION

ASHRAE Journal

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ROOM PRESSURE



FOR CRITICAL ENVIRONMENTS

By Brian Wiseman, P.E., Member ASHRAE

An HVAC design area that has not yet developed a standard "rule-of-thumb" is the quantitative determination of differential pressure and airflow for "proper" room pressurization. This article investigates current design guidelines and field practices for room pressurization. In particular, the author explores current literature that addresses the definition of "proper" pressurization.

The article then examines some practical in-field design considerations for two types of facilities, a tuberculosis BSL-3 research lab and a health-care hematopoietic stem cell transplant unit. In addition to field tests, the author provides a methodology for practitioners for verifying airflow direction, into or out of the room. The author concludes with recommended guidelines or "rules-of-thumb" values that may be a useful reference in designing rooms that require a proper negative or positive pressure.

Review of Literature and Guidelines

Chapter 12 in the *2001 ASHRAE Handbook — Fundamentals* provides a good treatise on air contaminants. Common room contaminants to be contained include airborne/aerosolized infectious diseases in hospitals and vivariums; chemical and biological spills in laboratories; and explosive dusts in manufacturing facilities.

Common rooms that strive to exclude contaminants include protective isolation rooms in hospitals for immunocompromised patients; clean rooms for industrial and pharmaceutical manufacturing; barrier rooms for nude mice in vivariums; and food-processing rooms in a food supply facility. The method to achieve directional airflow is via the control of the supply and exhaust airflows within and adjacent to the concerned room.

The salient question is how much the differential airflow should be to achieve "proper" room pressurization/directional airflow? This leads to the prerequisite question: What is "proper" pressurization/directional airflow?

Room Pressurization Fundamentals

Room pressurization depends on the ability of air to build up within a room. The leakage into or out of room is a key factor. Chapter 26 of the *2001 ASHRAE Handbook—Fundamentals* presents a leakage function relationship that correlates a room or building envelope air leakage to the differential pressure producing the flow.

ASHRAE defines the leakage function with the presentation of the "power law equation" (Equation 32) as:

$$Q = c(\Delta P)^n$$

About the Author

Brian Wiseman, P.E., is president of Airflow Direction Inc., Saugus, Mass.

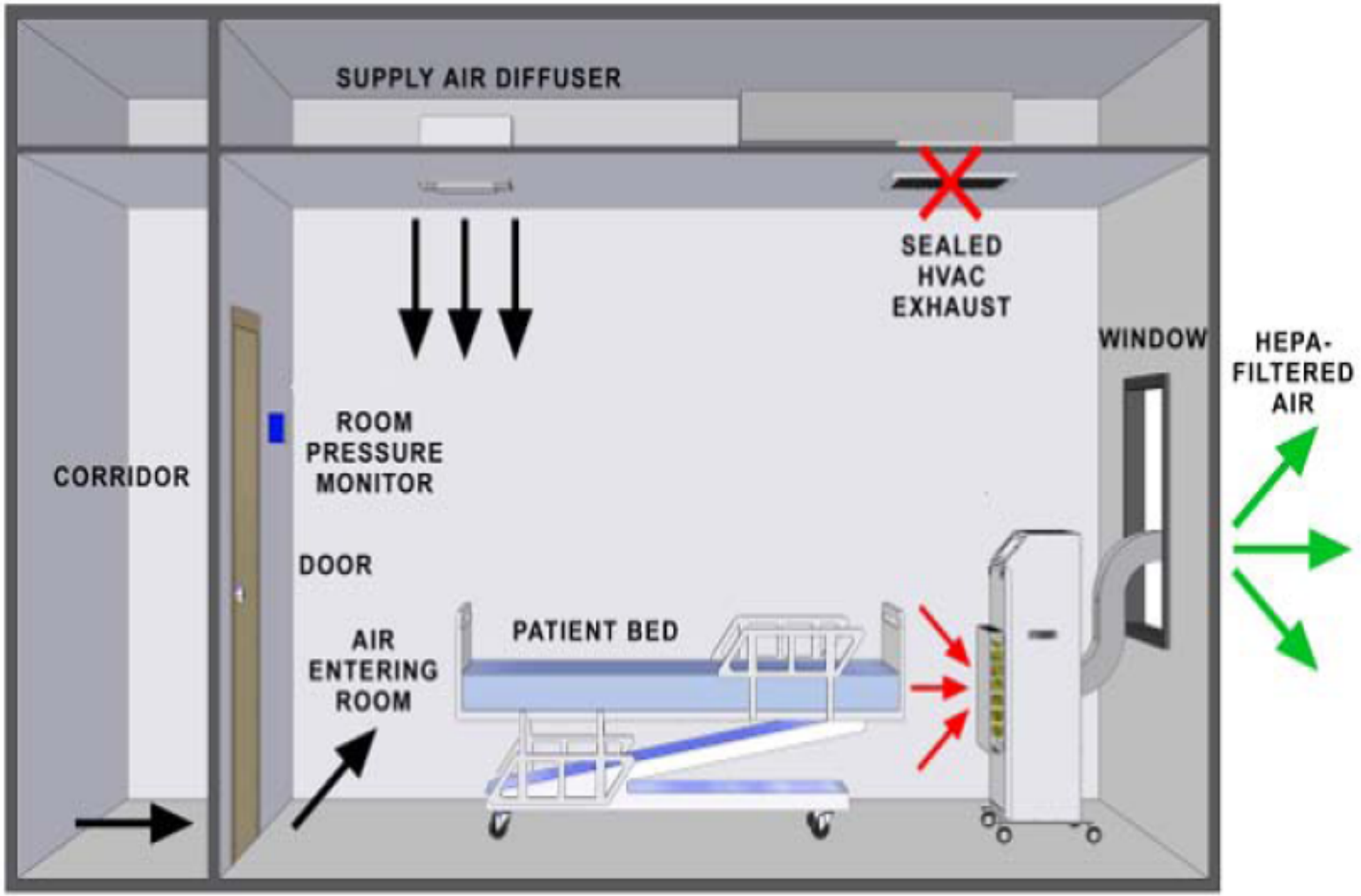

SUPPLY AIR DIFFUSER
SEALED
HVAC
EXHAUST
WINDOW
HEPA-
FILTERED
AIR
CORRIDOR
ROOM
PRESSURE
MONITOR
DOOR
AIR
ENTERING
ROOM
PATIENT BED

Table 3 Ventilation Requirements for Areas Affecting Patient Care in Hospitals and Outpatient Facilities

Function Space	Pressure Relationship to Adjacent Areas[a]	Minimum Air Changes of Outside Air per Hour[b]	Minimum Total Air Changes per Hour[c]	All Air Exhausted Directly to Outside[m]	Air Recirculated Within Room Units[d]	Relative Humidity,[n] %	Design Temperature,[o] °F
Surgery and Critical Care							
Operating room (recirculating air system)	Positive	5	25	—	No	45 to 55	62 to 80
Operating/surgical cystoscopic rooms[e, h, q]	Positive	5	25	—	No	45 to 55	68 to 73[r]
Delivery room[p]	Positive	5	25	—	No	45 to 55	68 to 73
Recovery room[p]	*	2	6	—	No	45 to 55	75 ± 2
Critical and intensive care	*	2	6	—	No	30 to 60	70 to 75
Newborn intensive care	*	2	6	—	No	30 to 60	72 to 78
Treatment room[s]	*	—	6	—	—	30 to 60	75
Nursery suite	Positive	5	12	—	No	30 to 60	75 to 80
Trauma room[f, s]	Positive	5	12	—	No	45 to 55	62 to 80
Anesthesia gas storage	Negative	—	8	Yes	—	—	—
GI Endoscopy	Negative	2	6	—	No	30 to 60	68 to 73
Bronchoscopy[q]	Negative	2	12	Yes	No	30 to 60	68 to 73
Emergency waiting rooms	Negative	2	12	Yes	—	30 to 60	74 ± 2
Triage	Negative	2	12	Yes	—	—	70 to 75
Radiology waiting rooms	Negative	2	12	Yes[t, u]	—	—	70 to 75

Optimal Space Conditions

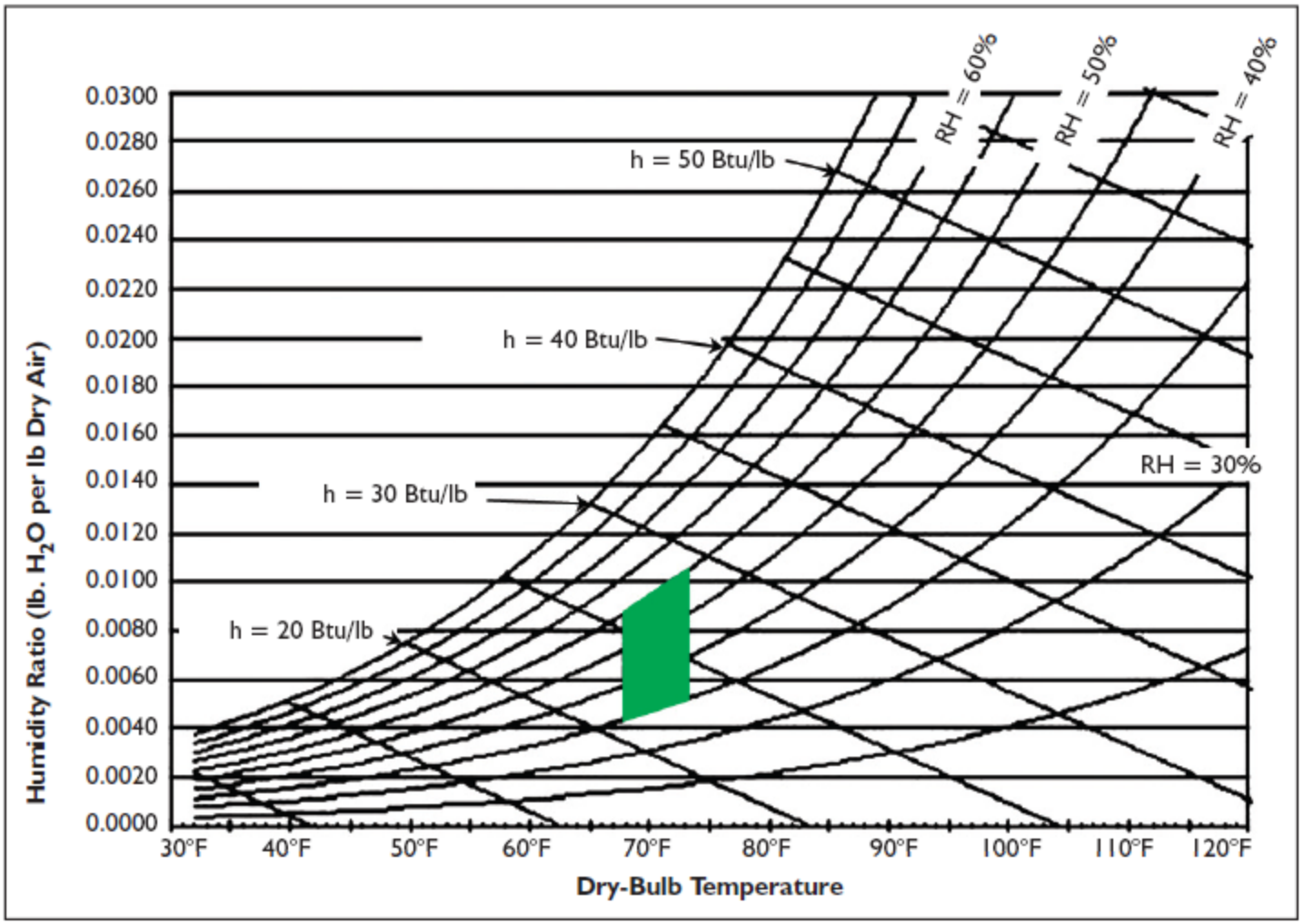


Figure 1: Psychrometric chart, indicating zone of acceptable operating room space conditions.

OPERTING ROOMS & LASER SURGERY AREAS

CDC Recommendations
Maintain positive pressure with respect to corridors and adjacent areas (Category IB, IC). Maintain 15 ACH or more, of which 3 or more ACH should be fresh air. (IC)
Use portable HEPA filtration units for supplemental air cleaning during intubation and extubation. Position the room units so that all room air passes through the filter; switch off the unit during the procedure. (Category II)
Use a mechanical smoke evacuation system with a high efficiency filter to manage the generation of large amounts of laser plume when ablating tissue infected with human papiloma virus (HPV) or performing procedures on a patient with extrapulmonary TB. (Category II)

NEGATIVE PRESSURE PATIENT ISOLATION

CDC Recommendations
Maintain continuous negative pressure (0.01 inch or 2.5 Pa) in relation to the air pressure in the corridor. (Category IB, IC)
Monitor air pressure periodically, preferable daily, with audible manometers or smoke tubes at the door (existing All rooms), or with a permanently installed visual monitoring mechanism. Document results. (Category IB, IC)
Provide ventilation to ensure 12 or more ACH for new or renovated rooms, and 6 or more ACH for existing rooms. (Category IB, IC)
Where supplemental engineering controls for air cleaning are indicated from a risk assessment of the area, install UVGI units in the HVAC exhaust ducts to supplement HEPA filtration, or install UVGI fixtures near the ceiling to irradiate upper room air. (Category II)

Place smallpox patients in negative pressure rooms at the onset of their illness, preferably in a room with an anteroom. (Category II)
Direct exhaust for All rooms to the outside, away from air intakes. If this is not practical, air from the room can be recirculated after passing through a HEPA filter. (Category IC)
Use All rooms for patients with or suspected of having an airborne infection and use cough-inducing procedures, or use an enclosed booth that is engineered to provide: 12 or more ACH; 0.01 in. (2.5 Pa) negative pressure; and air exhausted outside away from air intakes or traffic, or recirculated after HEPA filtration. (Category IB, IC)

TB GUIDELINES (2004)

"Healthcare settings serving populations with a high prevalence of TB disease may need to improve the existing general ventilation system or use air-cleaning technologies in general-use areas such as waiting rooms, emergency medical service areas, and radiological suites. Applicable approaches include: a) single-pass nonrecirculating systems that exhaust air to the outside, b) recirculation systems that pass air through HEPA filters before recirculating it into the general ventilation system, and c) room-air recirculation units with HEPA filters and UV systems."



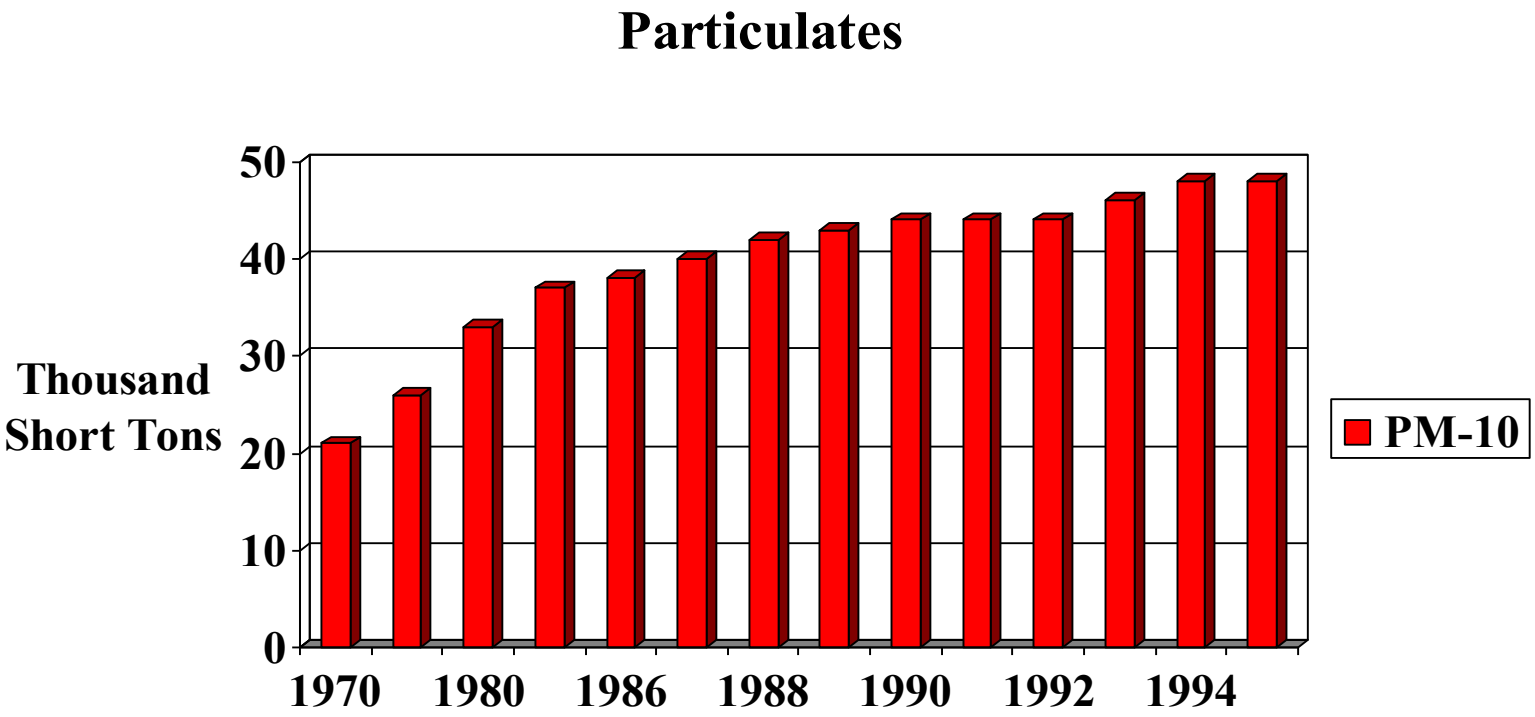
OUTDOOR SOURCE CONTROL
Ambient Air Quality

Regional outdoor air quality must be evaluated

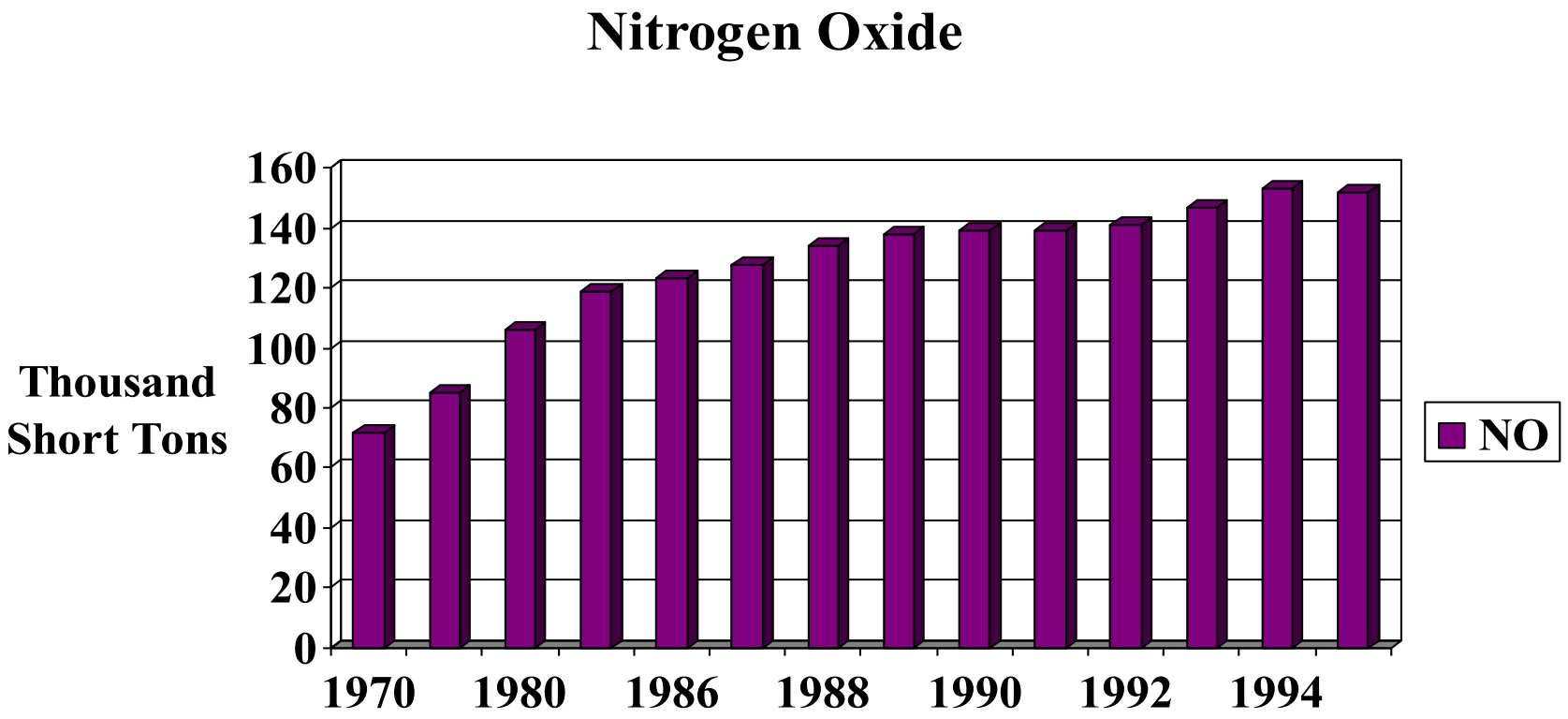
ASHRAE Std 62-2004: "4.1 Regional Air Quality. *The status of compliance with national ambient air quality standards shall be determined for the geographic area of the building site. In the United States, compliance status shall be either in "attainment" or "non-attainment" with …NAAQS…"*



North America EMISSION TRENDS (1970-1995)



North America EMISSION TRENDS (1970-1995)



NATIONAL PRIMARY AMBIENT-AIR QUALITY (for O.A. as set by the US EPA)

Pollutant	*Averaging Period*	*Standard*
Ozone (O_3)	1-hour	0.12 ppm
Carbon Monoxide (CO)	1-hour	9 ppm
	8-hour	35 ppm
Particulate Matter (PM-10)	24-hour	150 $\mu g/m^3$
	Annual arithmetic mean	365 $\mu g/m^3$
Sulfur Dioxide (SO_2)	24-hour	0.14 ppm
	Annual arithmetic mean	0.03 ppm
Nitrogen Dioxide (NO_2)	Annual arithmetic mean	0.53 ppm
Lead (Pb)	Annual arithmetic mean	1.5 $\mu g/m^3$

6.2.1 OUTDOOR AIR TREATMENT

If Outdoor Air is judged to be unacceptable in accordance with Section 4.1 (National Ambient Air Quality Standard), each ventilation system that provides outdoor air through a supply fan shall comply with sections following….

Key excerpts from ASHRAE Standard 62-2004

OUTDOOR SOURCE CONTROL

Intake Separation

Should separate intakes from strong outdoor sources

Vehicular traffic, helicopter landing pads

Minimum separation distance from intake for specific outdoor sources

Dumpster	15 ft
Cooling tower exhaust	25 ft
Loading dock	25 ft



VENTILATION RATES FOR HEALTHCARE

Appendix E: Table E-1

Application:	62–07 (visitor) Rp cfm/p
Patient Rooms @ 10p/1000 sf	**25**
Medical Procedure @ 20p/1000 sf	**15**
Operating Rooms @ 20p/1000 sf	**30**
Recovery / ICU @ 20p/1000 sf	**15**
Autopsy Rooms @ 20p/1000 sf	**0.50 CFM/Ft2**

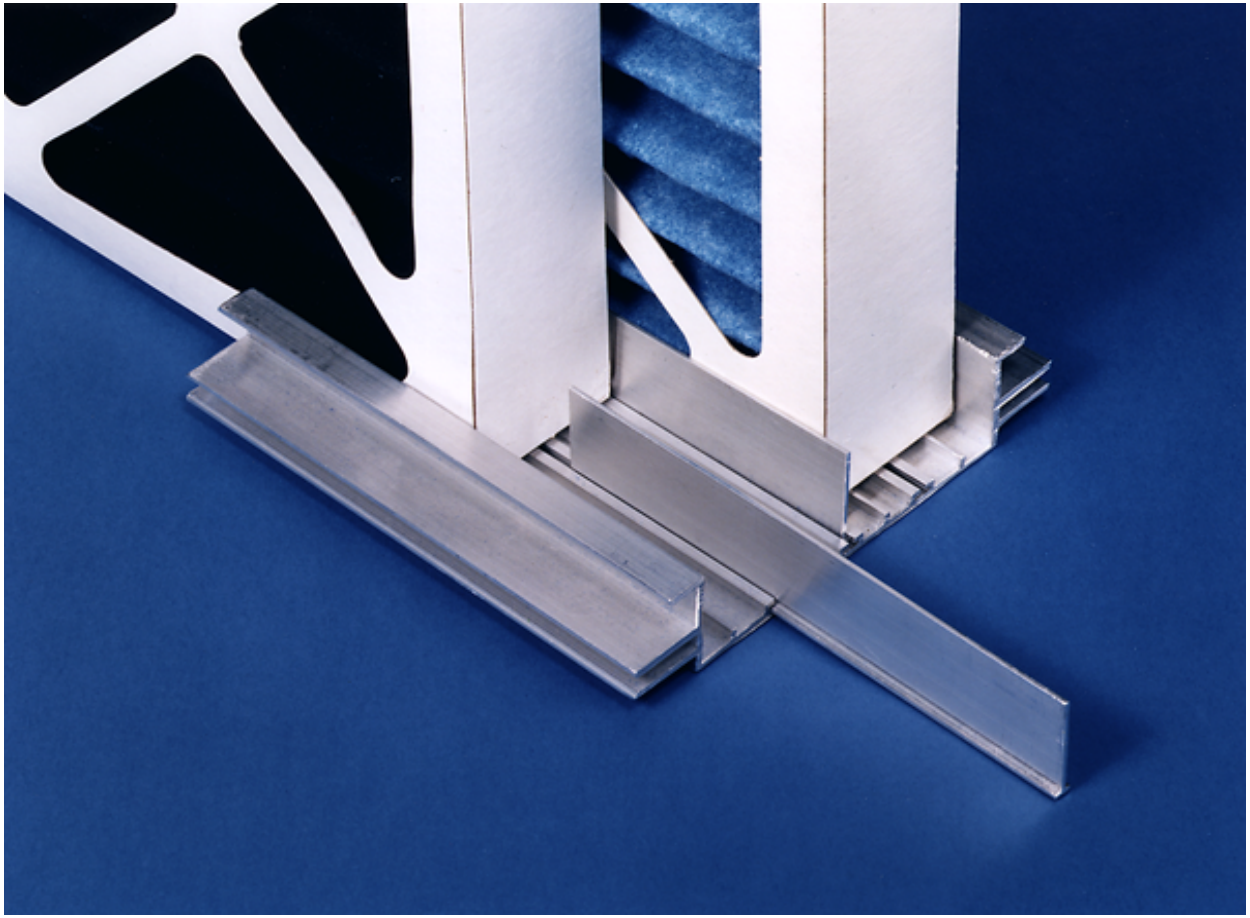
V_0

6.2.1.3 OTHER OUTDOOR CONTAMINANTS

When the building is located in an area where the national standard for one or more contaminants not specifically addressed in Section 6.2.1 is exceeded, any design assumption and/or calculation related to the impact on indoor air quality shall be included in the design documents.

Key excerpts from ASHRAE Standard 62-2004

Molecular Filtration



High Efficiency Gas Absorbers

- *Potassium Impregnated Alumina*
- *Coal Based Activated Carbon*



- *Activated Carbon Impregnated* with *Phosphoric Acid*

  Activated Carbon Impregnated with *Potassium Hydroxide*

Molecular Filtration for O.A.

Oxidation Reaction

Oxidant + Contaminant + Oxygen $\longrightarrow$ Carbon Dioxide + Water

Acid-Base Reaction

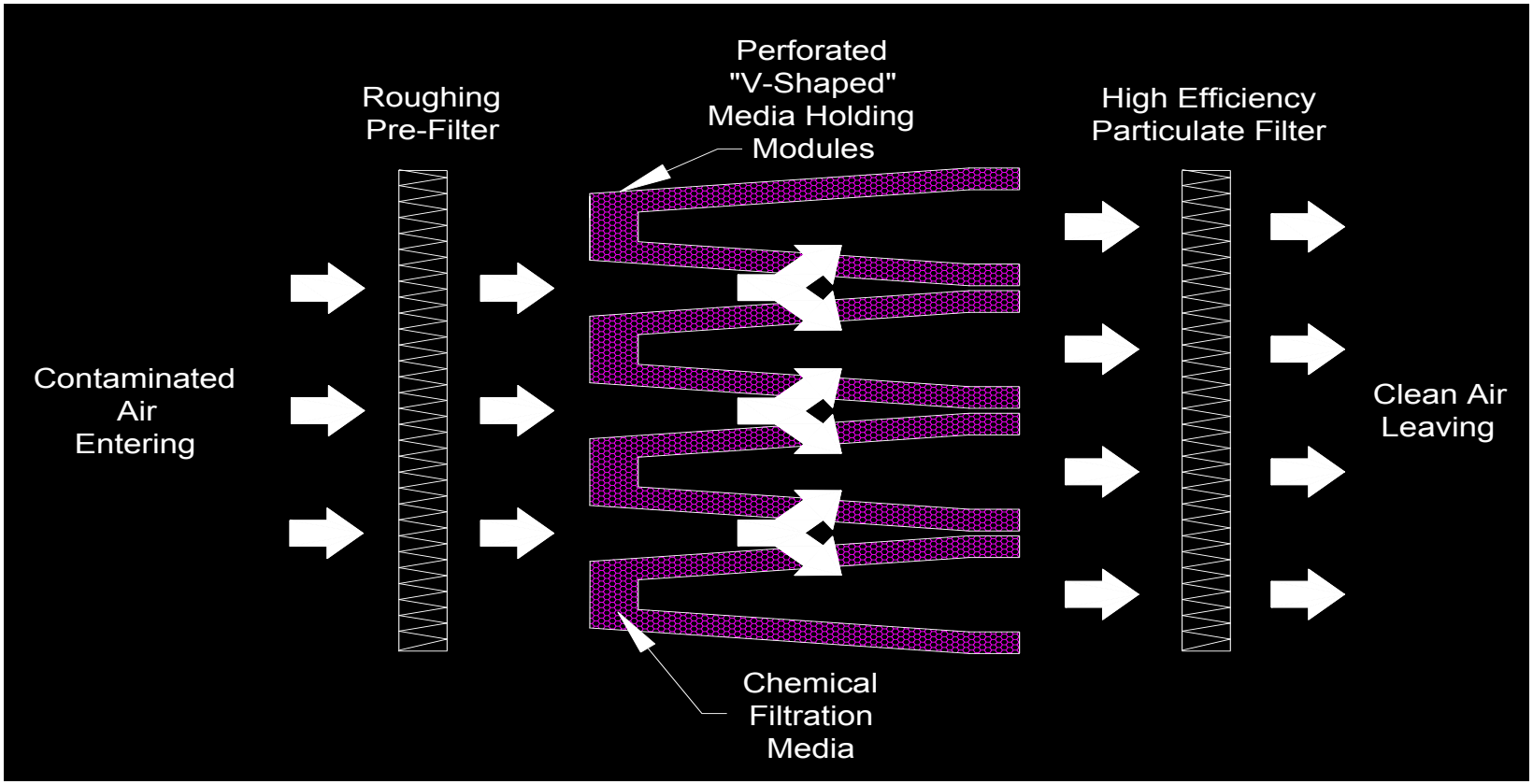
Acid + Base $\longrightarrow$ Salt + Water



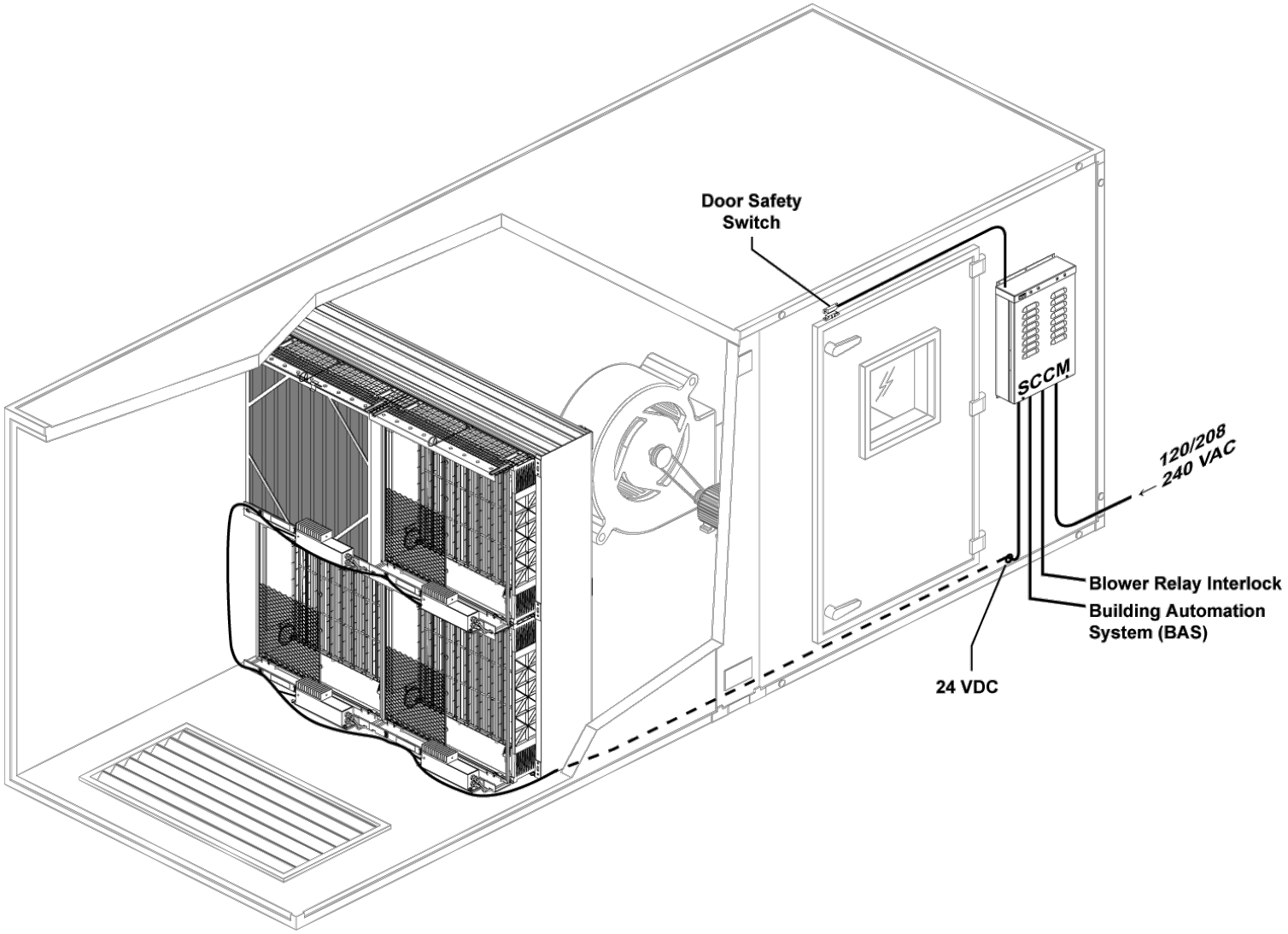


FLOW SCHEMATIC

THIN BED SYSTEM (T_{RS} L.T. 0.4s)

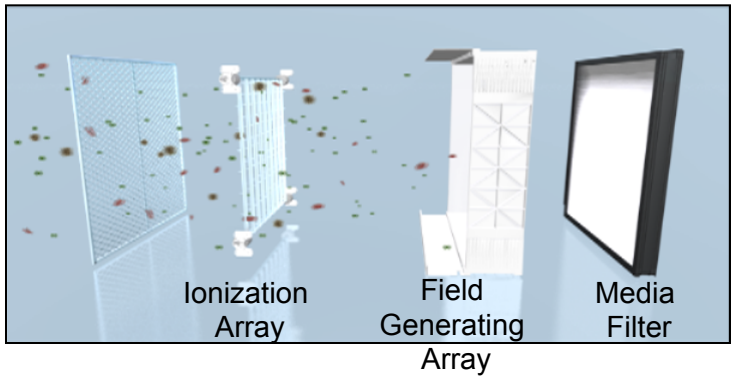


Custom AHU (Electronic Filtration)



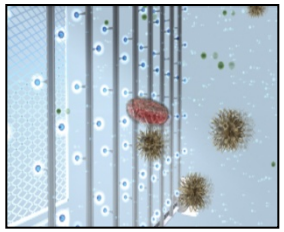
IONIZATION ARRAY

Air Flow



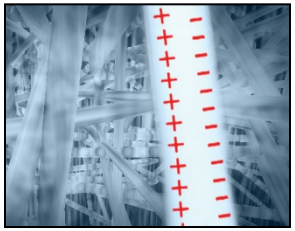
Performance verified by independent lab testing

1 – Charge



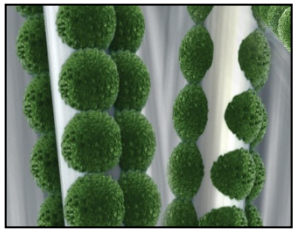
Incoming particles are ionized

2 – Polarize



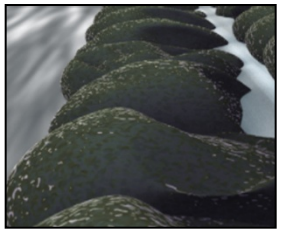
Voltage across the field array polarizes the media fibers

3 – Capture

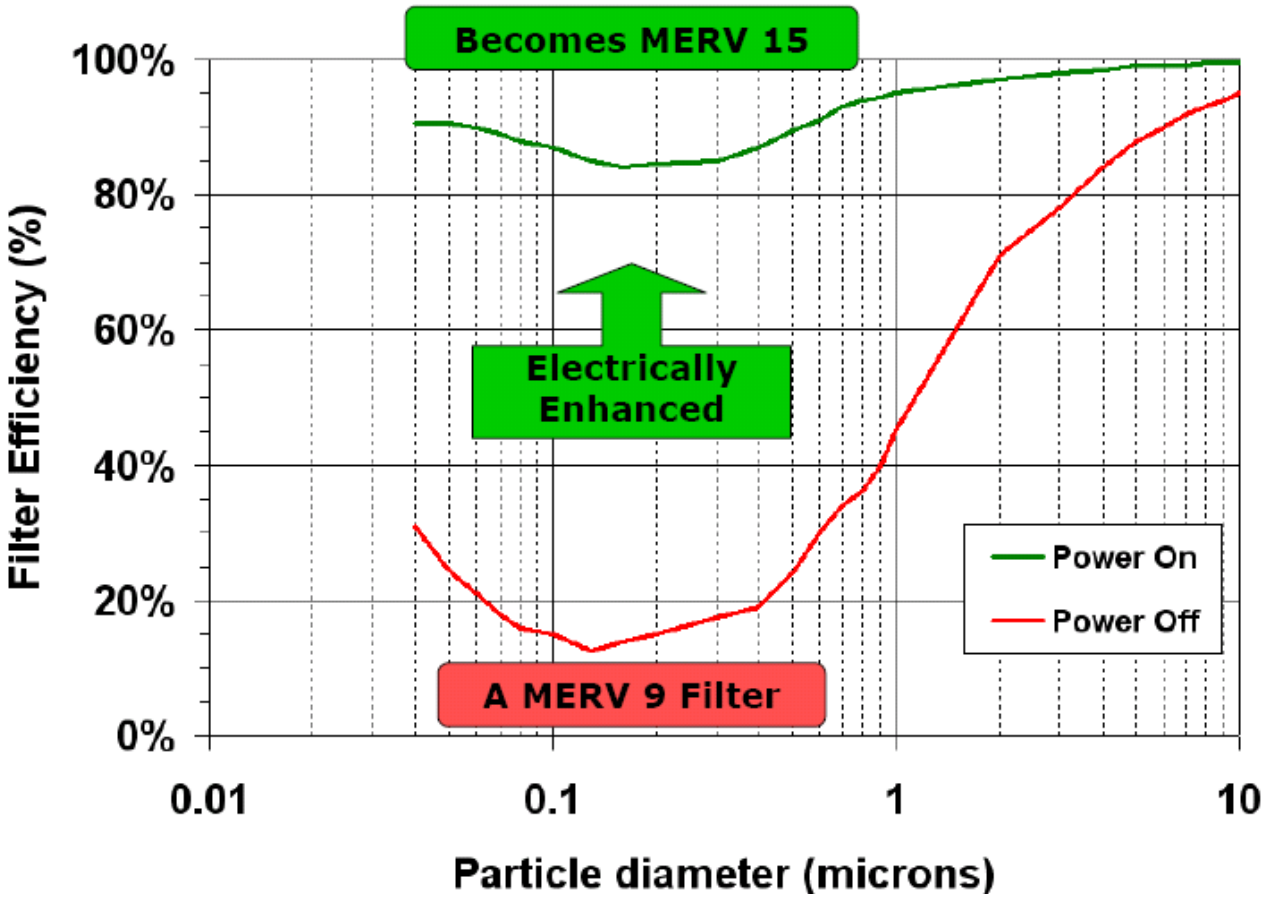


Charged particles are attracted to fibers

4 – Kill



Electric field effect in filter destroys biological contaminants


Becomes MERV 15
Electrically Enhanced
A MERV 9 Filter
Power On
Power Off
100%
80%
60%
40%
20%
0%
Filter Efficiency (%)
0.01
0.1
1
10
Particle diameter (microns)

HEALTHCARE FACILITIES

Air Quality and The Indoor Environment



AIR QUALITY STUDIES

Findings GSA study

- 70% airborne, 63% not visible
- 100 microns of dust on coil cuts cooling capacity 10%
- 20-30% increase in annual energy costs

Air filters

- Use pre-filters to extend the life of high cost filters
- MERV 8 / MERV 14 / HEPA

UVGI



ULTRAVIOLET GERMICIDAL IRRIDIATION UVGI



The germicidal wavelengths are located around 254 nanometers in the UV-C band

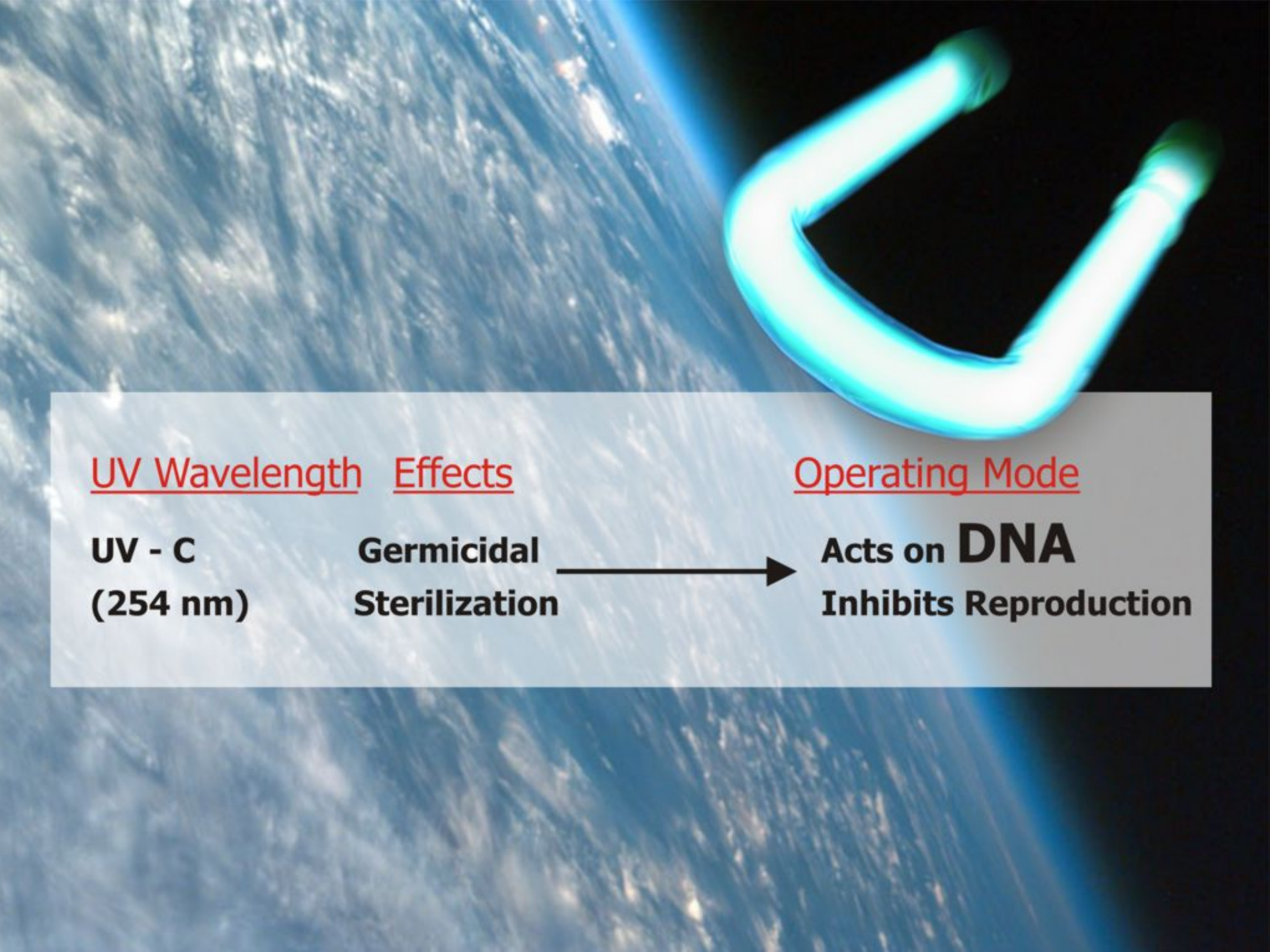
Controls fungi in HVAC systems to reduce or eliminate mold-related allergies

- Prevents the development of Legionella and other bacteria… a recognized control strategy for tuberculosis
- Predictably reduces the spread of cold and flu viruses and other airborne-transmitted diseases

Natural Source (The Sun)

DAILY germicidal UV DOSE received by a bacteria living in OUTDOOR AIR :

19,189 microwatt.sec/cm^2



UV Wavelength	Effects	Operating Mode
UV - C (254 nm)	Germicidal Sterilization	Acts on **DNA** Inhibits Reproduction

$$DOSE_{outdoor} := \frac{1}{400 - 300} \cdot \int_{0 \cdot hr}^{12 \cdot hr} \int_{300}^{400} Eff_{germ}(\lambda) \cdot UV(\lambda)\ d\lambda\ dt$$

Total Daily Natural Outdoor UV Dose :

$$DOSE_{outdoor} = 19189\ \frac{microwatt \cdot sec}{cm^2}$$

Minimum Germicidal UV output power requirement per square foot of indoor floor assuming 24/24 continuous use :

$$Spec_{sqft_output} := \frac{DOSE_{outdoor}}{24 \cdot hr}$$

$$Spec_{sqft_output} = 206\ \frac{microwatt}{ft^2}$$

CHILDREN'S HOSPITAL SUNY BUFFALO
Neonatal Intensive Care Unit

Serial bacterial and fungal cultures on HVAC system and tracheal aspirate (TA) from intubated infants

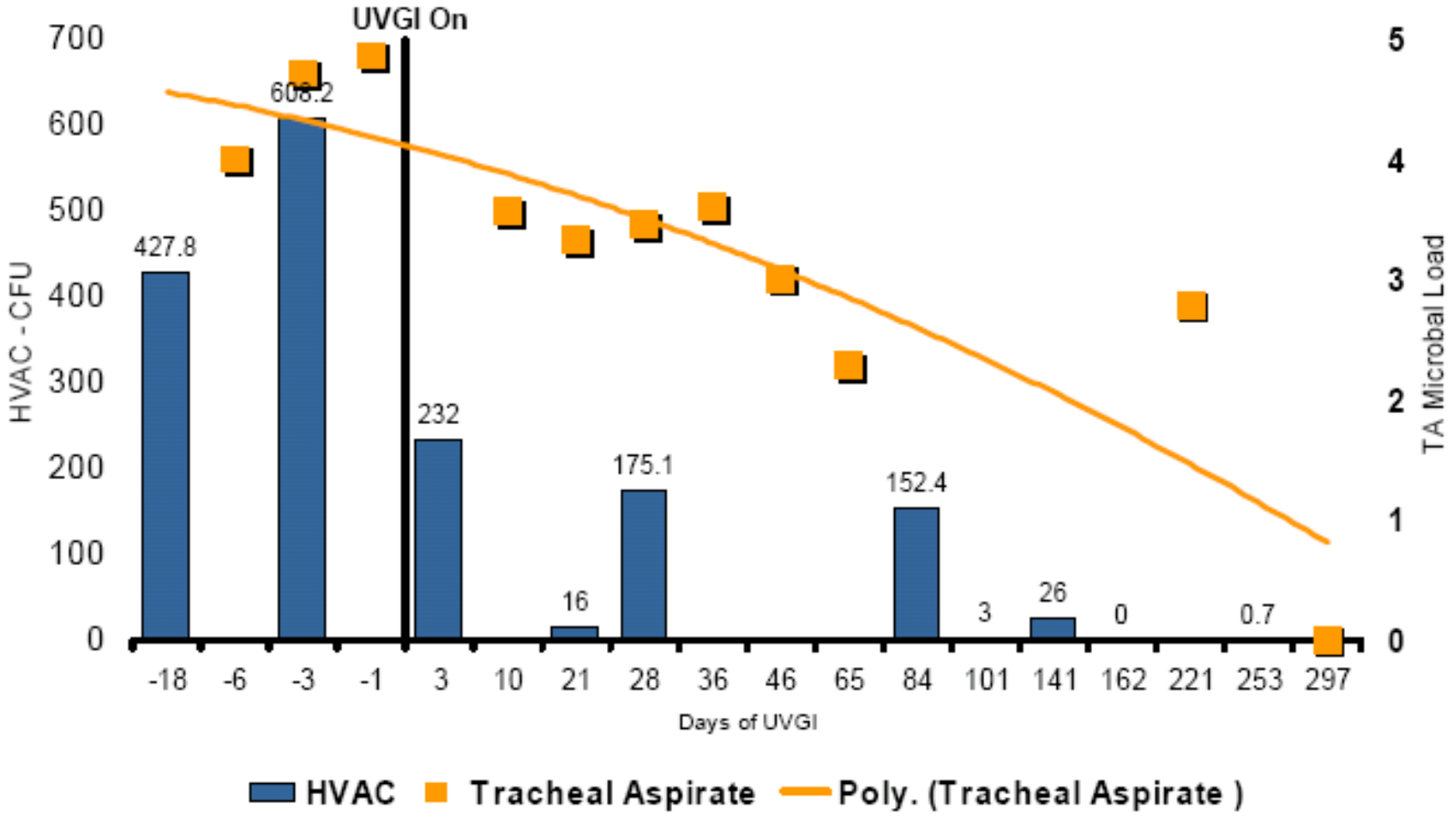
Microbes isolated from HVAC system were identical to those in NICU and TA

- Pseudomonas, Klebsiella, Bacillus and Serratia

After UVGI was installed total microbial load markedly decreased



UVGI PERFORMANCE



Source: Dr. C. Leach, Dr. R. Ryan

Dosage of UV-C for complete destruction (uW-sec/cm^2)

BACTERIA			
Agrobacterium Lumefaciens^	8,500	Streptococcus Lactis*	8,800
Bacillus Anthracis*(**Anthrax**)	8,700	Streptococcus Pyrogenes^	4,200
Bacillus Anthracis ***Spores***^(**Anthrax**)	46,200	Streptococcus Salivarius^	4,200
BaciHus Megatherium Sp. (Veg)*	2,500	Streptococcus Viridans*	3,800
Bacillus Megatherium Sp. (Spores)*	5,200	Typhoid Fever^	4,100
Bacillus Paratyphosus*	6,100	Vibrio Comma (Cholera)^	6,500
Bacillus Subtilis*	11,000	Vibrio Cholerae^	6,500
Bacillus Subtilis Spores*	22,000	**MOLDS**	
Clostridium Tetani^	23,100	Aspergillus Amstelodami^	77,000
Clostridium Botulinum^	11,200	Aspergillus Flavus*	99,000
Corynebacterium Diphtheriae*	6,500	Aspergillus Glaucus*	88,000
Dysentery Bacilli*	4,200	Aspergillus Niger (bread mold)*	330,000
Eberthella Typhosa*	4,100	Mucor Mucedo^	77,000
Escerichia Coll*	8,600	Mucor Racemosus (A & B)*	35,200
Legionella Bozemanii^	3,500	Oospora Lactis*	11,000
Legionella Dumoffill^	5,500	Penicillium Chrysogenum^	56,000
Legionella Gormanil^	4,900	Penicillium Digitatum*	88,000
Legionella Micdadei^	3,100	Penicillium Expansum*	22,000
LegioneHa Longbeachae^	2,900	Penicillium Roqueforti*	26,400
Leglonella Pneumophfla		Rhizopus Nigricans (cheese mold)*	220,000
(Legionnaire's Disease)	2,760	**VIRUS**	
Leptospiracanicola-		Adeno Virus Type III^	4,500
Infectious Jaundice^	6,000	Bacterlophage (E.Coli)*	6,600
Leptospira Interrogans^	8,000	Coxsackie A2^	6,300
Micrococcus Candidus*	12,300	Infectious Hepatitis^	8,000
Micrococcus Sphaeroides*	15,400	Influenza*	3,400
Mycobacterlum Tuberculosis^	10,000	Rotavirus^	24,000
Neisseria Catarrhalis*	8,500	Poliovirus^	21,000
Phytomonas Tumefaciens*	10,500	Variola** (**Smallpox**)	24,000

Results from Studies

Montreal, Canada – In a study published in The Lancet Medical Journal, McGill University scientists found that shining UVGI on the air conditioning coil reduces over all sickness by 20%, reduces respiratory symptoms by 40% and has resulted in a 99% reduction of microbial and endotoxin concentrations on irradiated surfaces within the ventilation system.

McGill

McGill University Health Center

A two year Double Blind Study on Sick Building Syndrome using Totaline Ultraviolet Purifiers Published in The Lancet Medical Journal.

Department of Epidemiology and Bio-statistics of McGill University


Effect of ultraviolet germicidal lights installed in office ventilation systems on workers' health and wellbeing: double-blind multiple crossover trial

Dick Menzies MD MSc1, Julia Popa BEng MEng, James A Hanley PhD, Thomas Rand PhD, Don Milton MD DrPH.

TECHNOLOGY EVALUATION REPORT

Biological Inactivation Efficiency by HVAC In-Duct Ultraviolet Light Systems

The U.S. Environmental Protection Agency's (EPA's) National Homeland Security Research Center (NHSRC) Technology Testing and Evaluation Program (TTEP) is helping to protect human health and the environment from adverse impacts resulting from acts of terror by carrying out performance tests on homeland security technologies.

The objective of testing the device was to evaluate its bioaerosol inactivation efficiency as a heating, ventilation and air-conditioning (HVAC) in-duct ultraviolet light system.

TECHNOLOGY EVALUATION REPORT

Biological Inactivation Efficiency by HVAC In-Duct Ultraviolet Light Systems

The bioaerosol inactivation efficiencies calculated for the three organisms were 93% for *B. atrophaeus*, $99.97% for *S. marcescens* and 99% for MS2. The irradiance was measured as 1200 µW/cm2 at 133 cm (52.4 in.) upstream from the closest glass part of the lamps with an airflow of 0.93 m3/sec (1970 cfm). The system had five lamps that were burned in for 100 hours prior to measurements.

MANAGE CONDENSATE

To avoid “spitting” in draw-thru units, drain lines must seal

Std 62-2004: *“**5.11.3 Drain Pan Seal.** …the drain line shall include a P-trap or other sealing device designed to maintain a seal against ingestion of ambient air…whether the fan is on or off.”*

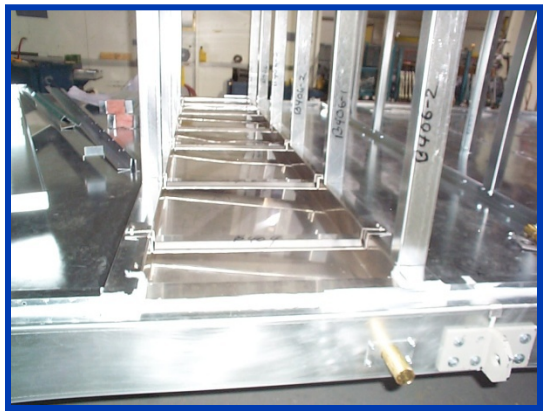
AHU CONSTRUCTION DETAILS

Drainage systems

304 Stainless steel drain pan for coil condensate

Recessed floor sections with 2 in or 4 in depth

Sloped drains per AHU section for washing capability







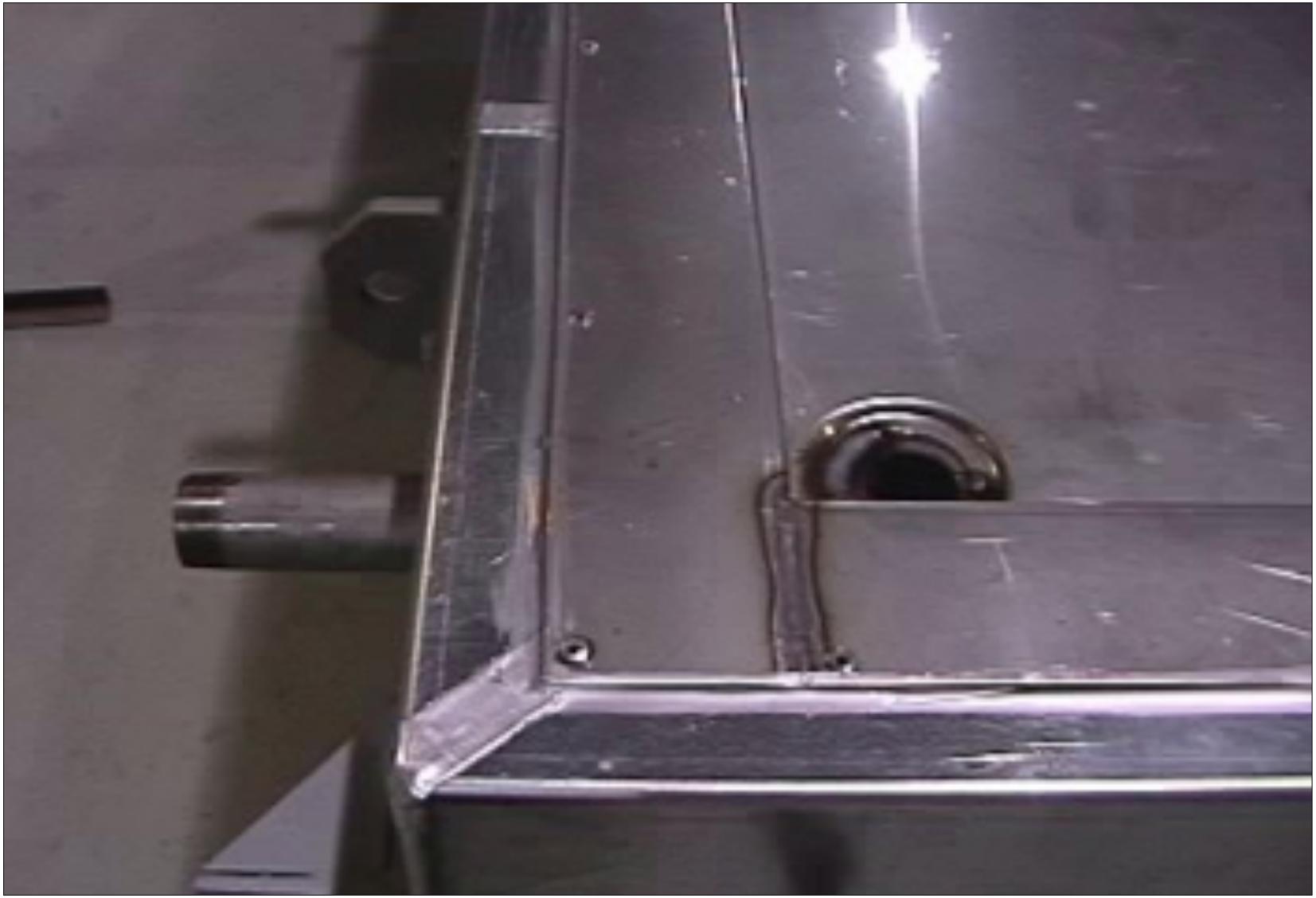
WASHDOWN CONSTRUCTION



FILTRATION SECTION



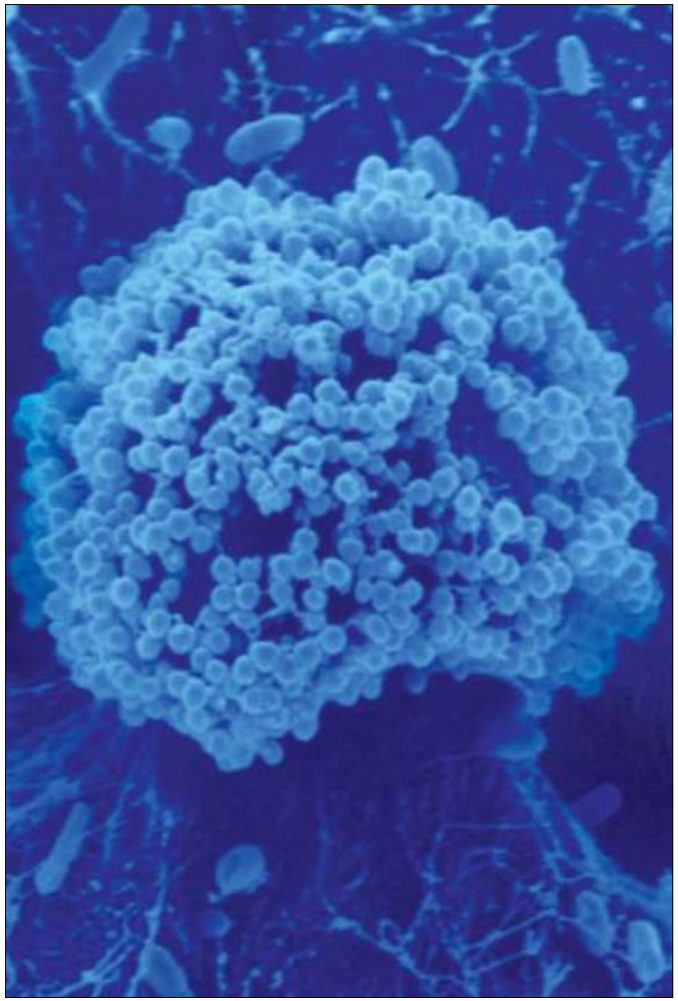
HUMIDIFIER SECTION DRAINAGE



WASHDOWN BLOWER SECTION



Agion® ANTIMICROBIAL STEEL

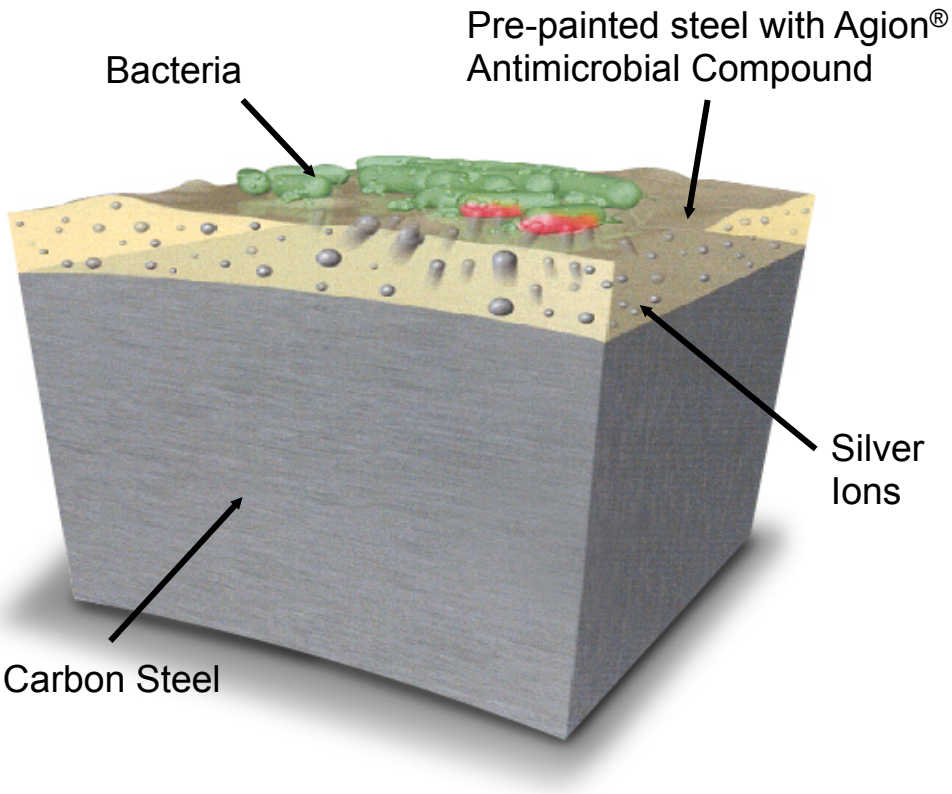


Agion® is a patented zeolite matrix that is incorporated into the steel of the AHU wall liner system. It uses the natural protective qualities of elemental silver ion as the active ingredient for suppressing microbial growth.

HOW DOES Agion® WORK?

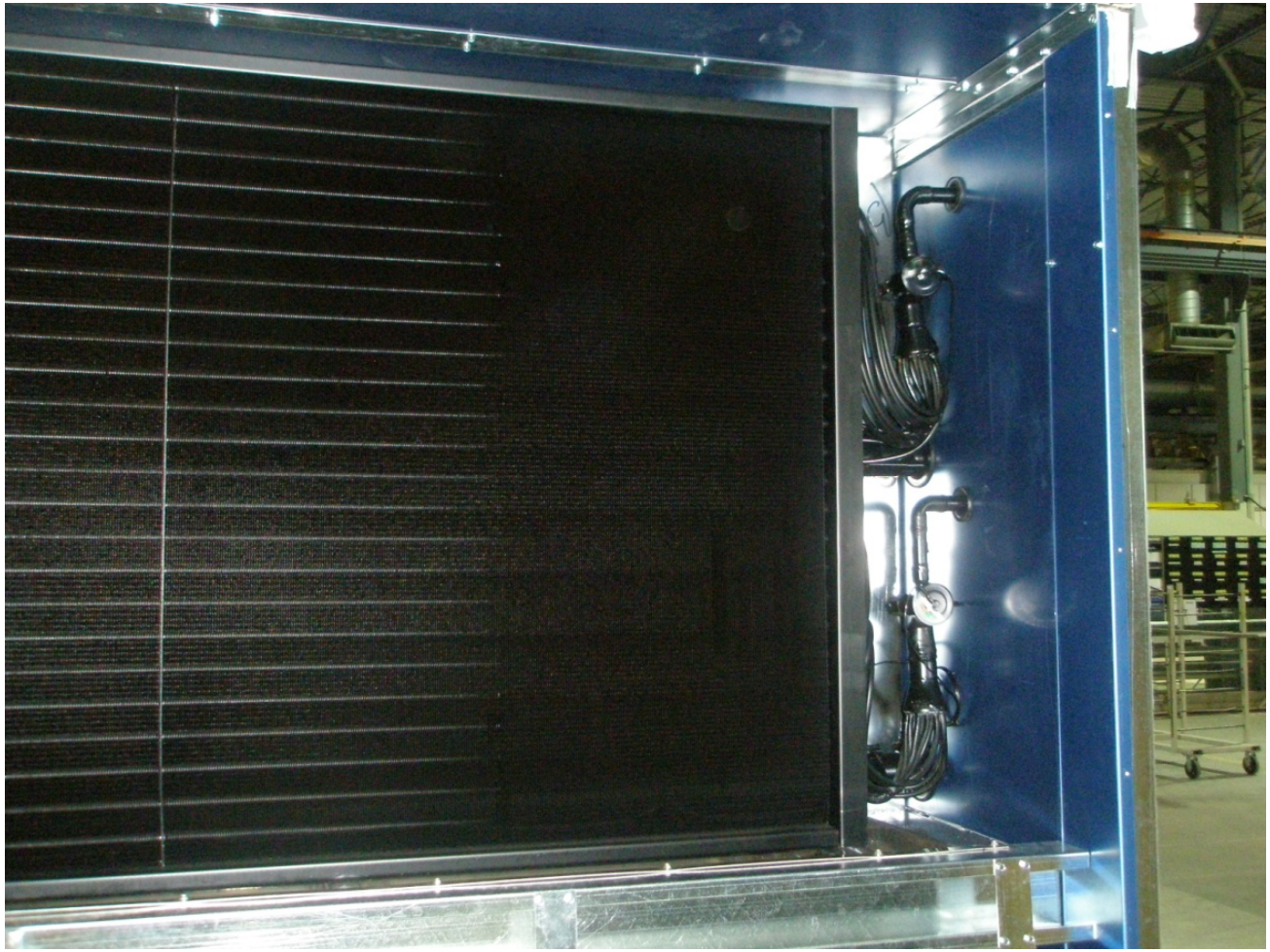
The zeolite matrix allows for the slow, controlled release of silver ions. When silver ions come into contact with bacteria and other microbes, the interaction disrupts electron transfer and cellular respiration which inhibits the growth of microbes on the treated surface.

Listed with the U.S. F.D.A. and registered with the Environmental Protection Agency.



For more info: http://www.agion-tech.com.

Aglon Inner Liner



CASE STUDY

Buffalo General Hospital



Buffalo, NY

Common plenum and service corridor

ASHRAE 30%, HEPA 99.97%

CASE STUDY
St. Luke Hospital



Milwaukee, WI

MERV 6, 13

Stacked units

CASE STUDY

Sharp Hospital
O.A / R.A. with Filtration

Outdoor air filtration to remove harmful pollutants such as NO_x, SO_x, O_3 and HC

MERV 6

MERV 13

UVGI

Activated Carbon Cells

HEPA (MERV 16)



SHARP San Diego's Health Care Leader

CASE STUDY

St. Francis, Indianapolis
O.A / R.A. with Filtration

Outdoor air filtration to remove harmful pollutants such as NO_x, SO_x, O_3 and HC

MERV 8

MERV 13

UVGI

MERV 16



CASE STUDY

Washoe Medical Center, Nevada
Gas filtration



Helicopter landing pad

O.A. filtration of Hydrocarbons, particulates

Respiratory difficulties

Chemical Filtration / HEPA particulate filtration

Washoe Medical Center
The healing power of people.

CASE STUDY

Clinic OVO Montreal, Canada
Fertility clinic O.A./R.A. filtration

Fertility Clinic

Central AHU total filtration system

12,500 CFM O.A./R.A filtered

MERV 8 / chemical filters / UV/ HEPA



OVO
FERTILITY CLINIC

CASE STUDY

Forensic Pathology, Toronto
Biological / Chemical Filtration

Chief Coroner Office Ontario

Main body storage area, pathology center

20-40 ACH

Combines UV / Chemical Filtration / HEPA particulate filtration



CASE STUDY

HIV Dental Clinic, Albany, NY
Dedicated Filtration in Dental Surgery Areas

Protect HIV patients from airborne contamination

Filter Gases, Particulates, Biological Contaminants

Maintain positive pressure 0.1” W.C. within Dental Surgery Area



Case Study

- Williamsport Central Med (PA)







Case Study

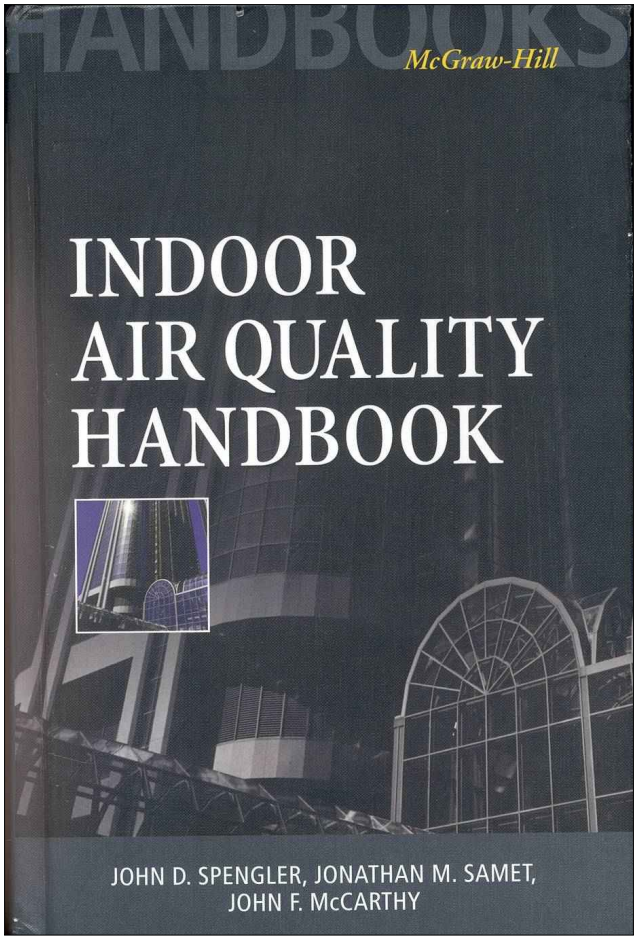
- Williamsport Central Med (PA)





CONTINUOUS IAQ MONITORING





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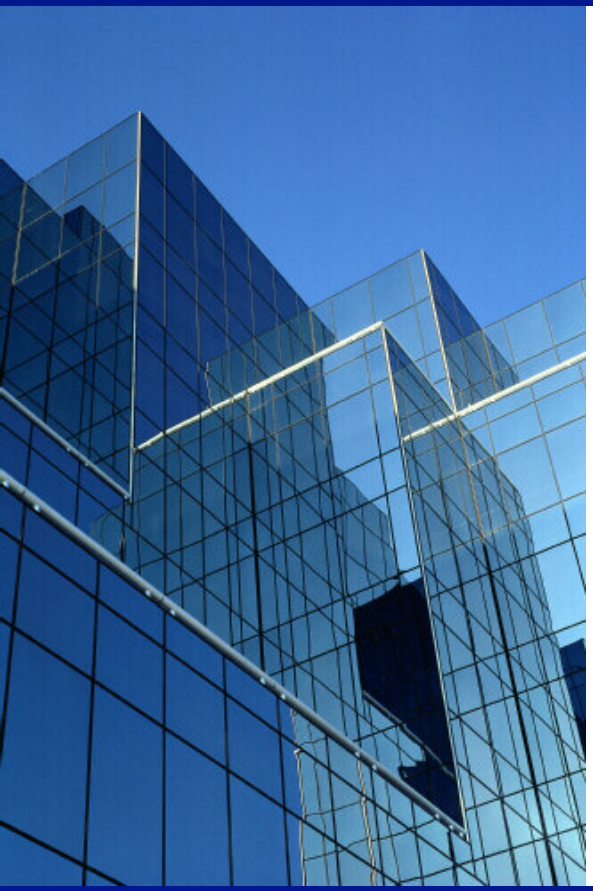
Hospital Filtration Systems: Airborne Contaminant Control

Brian Monk, P. Eng. , ASHRAE DL

ASHRAE Singapore

Shaping Tomorrow's Built Environment Today

Dedicated Outdoor Air Systems and ASHRAE Standard 62.1



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United Technologies
Climate | Controls | Security

ASHRAE Singapore

ASHRAE Will Give You The World

NETWORK

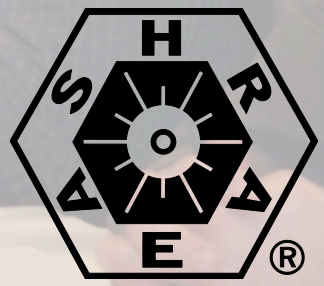
Give Back To ASHRAE

GROW

LEARN

TEACH

SHARE



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- ✔ **Compile the attendee rating on the Event Summary Critique**
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Summary of Presentation

- Outdoor Air (Standard 62.1)
- Energy Recovery Technology
- DOAS Configurations
- Engineering Evaluation
- Control Strategies
- DOAS and Chilled Beam



Benefits of Energy Recovery

- Environmental and Sustainable Design Practice
- Lower Life Cycle Costs
- Improved Indoor Air Quality
- Compliance with National Building Codes and Standards (ASHRAE 90.1)



Origins of Energy Recovery

- Increased energy costs since the oil embargo of the early 1970s
- Lack of natural resources has had a major influence on the design and operation of buildings worldwide.



Effects of Increased Energy Costs on Design

Design Decision:

- Tighter building envelopes
- Reduced amounts of outdoor air introduced into the space.

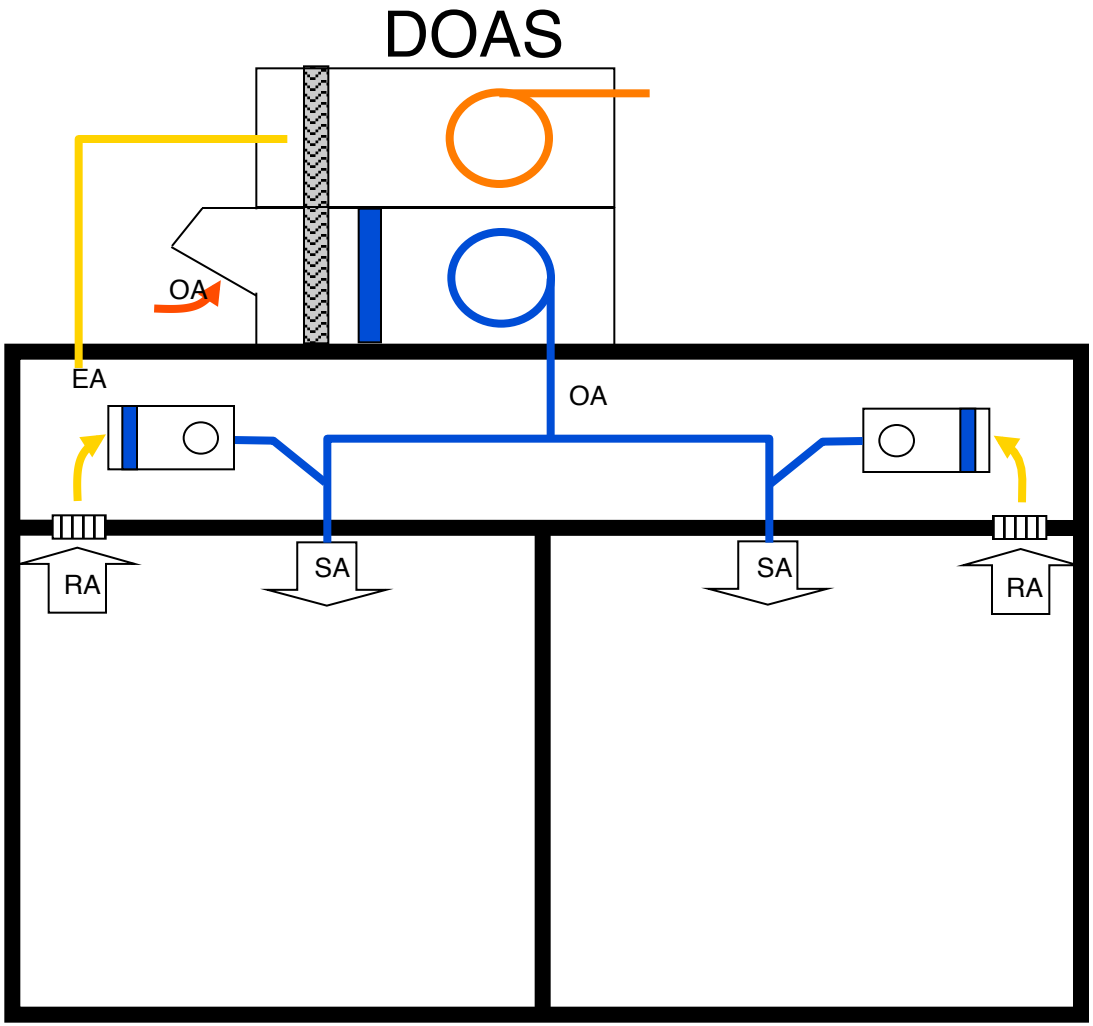
Result:

- Occupant discomfort
- Poor indoor air quality
- Sick Building Syndrome
- Reduced Productivity

Dedicated Outdoor Air Systems

1. 100% OA delivered to each zone via its own ductwork
2. Flow rate generally as spec. by ASHRAE Std. 62.1 or greater (LEED)
3. Employ Total Energy Recovery (ASHRAE 90.1)
4. Generally Constant Volume
5. Use to decouple space S/L loads
6. Rarely supply at a neutral temperature
7. Use HID, particularly where parallel system does not use air

FCU/DOAS arrangement



DOAS Concept

Dedicated outdoor air systems (DOAS) can reduce energy use by decoupling the heating, cooling, and dehumidification of OA for ventilation from sensible cooling and heating in the zone. The OA is conditioned by a separate dedicated OA unit that is designed to heat, cool, and dehumidify the OA, and to deliver it dry enough to offset space latent loads (Mumma and Shank 2001). Terminal HVAC equipment, which is located in or near each space, heats or cools recirculated indoor air to maintain space temperature. Terminal equipment may include fancoil units, WSHPs, zone-level air handlers, radiant cooling panels, fan-powered VAV terminals, or a dual-fan, dual-duct arrangement. Dedicated OA systems can also be used in conjunction with multiple-zone recirculating systems, in which the ventilation system is sized based on ASHRAE Standard 62.1.

DOAS Concept

- Consider delivering the conditioned OA cold (not reheated to neutral) whenever possible, and use recovered energy to reheat only when needed. Providing cold (rather than neutral) air from the dedicated OA unit offsets a portion of the space sensible cooling loads, allowing the terminal HVAC equipment to be downsized and use less energy. In addition, implementing system-level control strategies and exhaust air energy recovery can help minimize energy use.
- There are many possible DOAS configurations The salient energy-saving feature of dedicated OA systems is the separation of ventilation air conditioning from zone air conditioning.

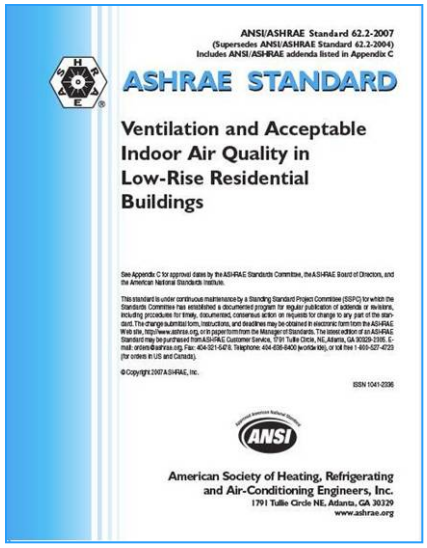
Pertinent Standards Adopted by Many Building Codes

- ASHRAE Standard 62.1, “Ventilation for Acceptable Indoor Air Quality”
- ASHRAE Standard 90.1, “Energy Efficient Design of New Buildings Except New Low-Rise Residential Buildings”

Building Codes & Standards

ANSI/ASHRAE Standard 62.1
Ventilation for Acceptable Indoor Air Quality

Application	*CFM/PERSON*
Class rooms	15
Offices	20
Smoking areas	60
Retail stores	15
Theatres	15
Bars	30
Banks	15
Metal shop	15

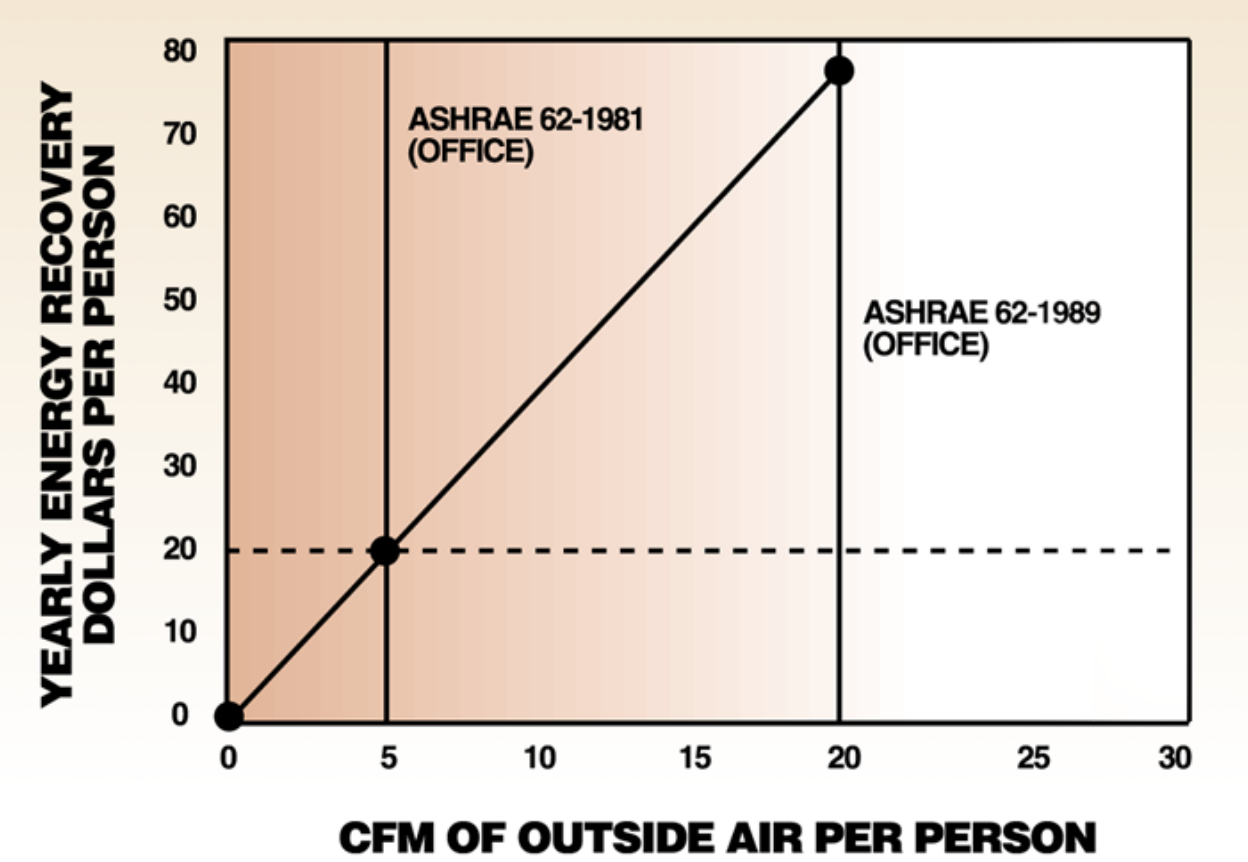


*LEED Can exceed rate by up to 30%

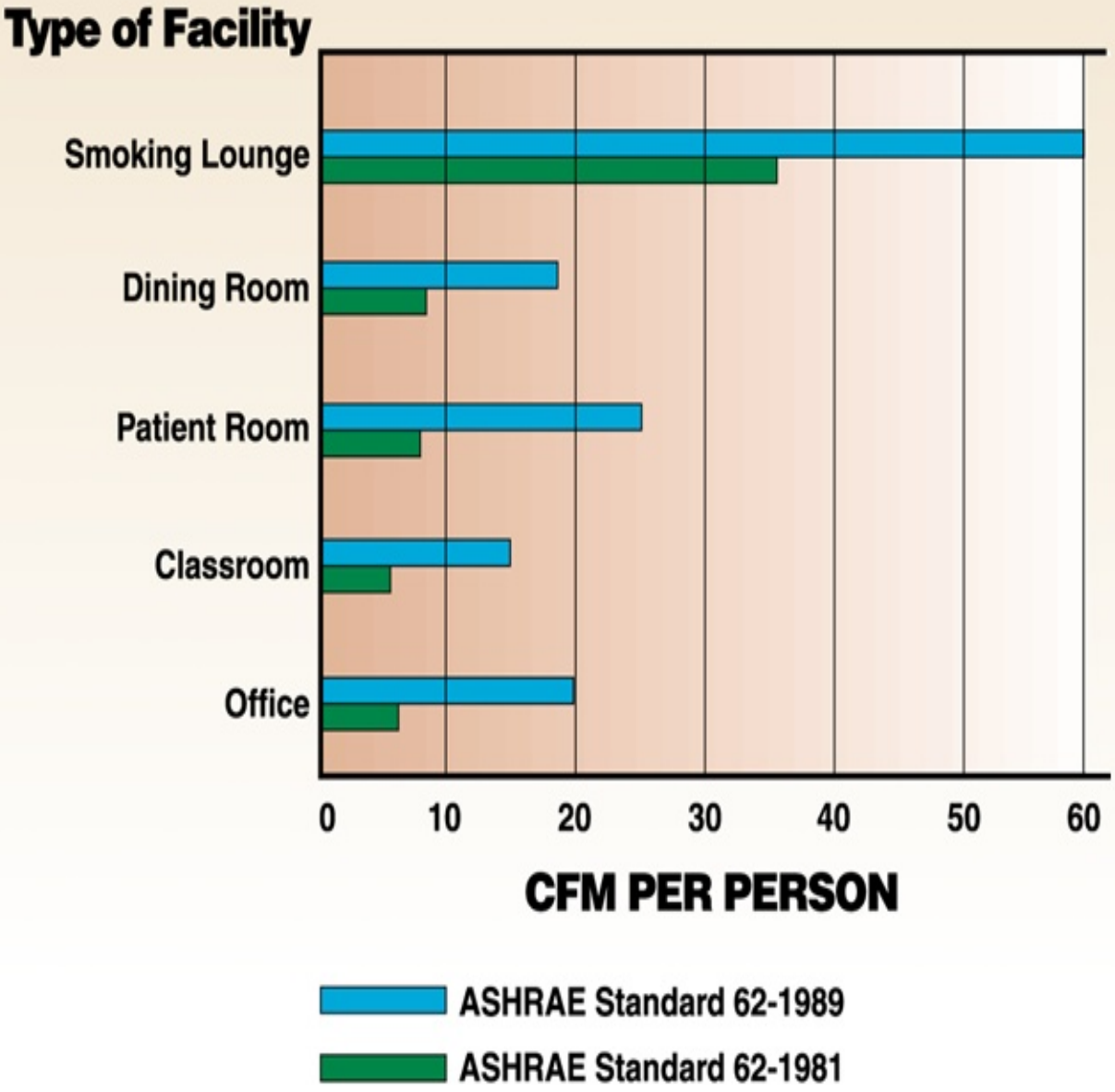
Updates:

- guidelines for analyzing mechanical cooling systems to help limit space relative humidity.
- Overall decrease in OA if overall space is greater than the number of occupants

Indoor Air Quality vs. Energy Cost (historically)



Outside Air


Type of Facility
Smoking Lounge
Dining Room
Patient Room
Classroom
Office
0
10
20
30
40
50
60
CFM PER PERSON
ASHRAE Standard 62-1989
ASHRAE Standard 62-1981

Ventilation Rates

- First, why introduce outdoor air?
  - To dilute and remove indoor contaminants
  - To replace indoor air removed by exhaust
- Second, how much outdoor air is needed?
  - For design, use IAQ Procedure, or
  - For design, use Ventilation Rate Procedure

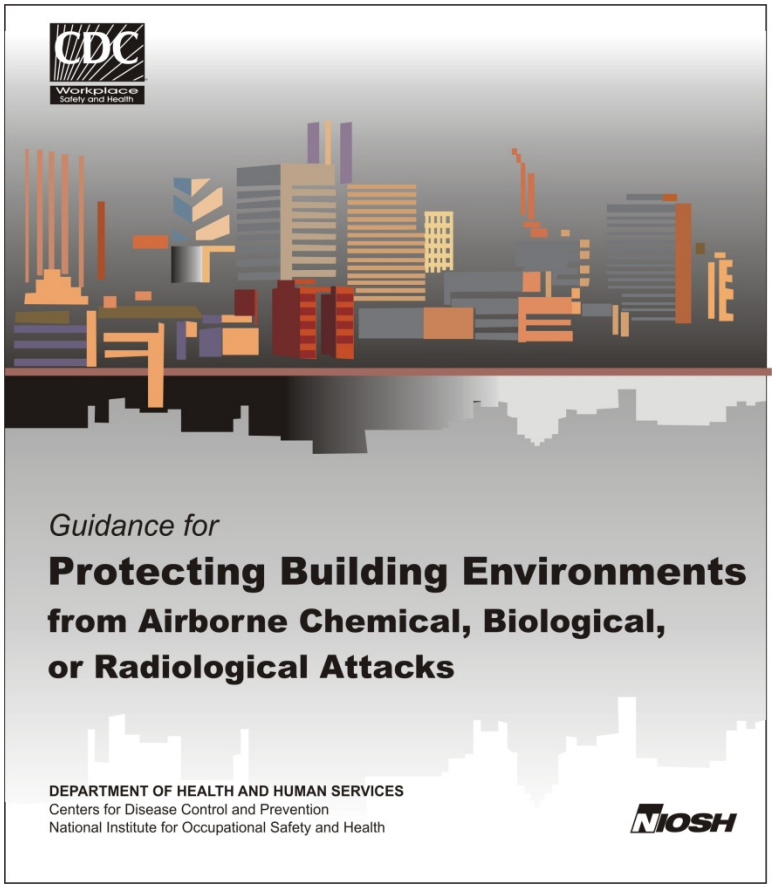
$$Vo = G/(C_i - C_o)$$

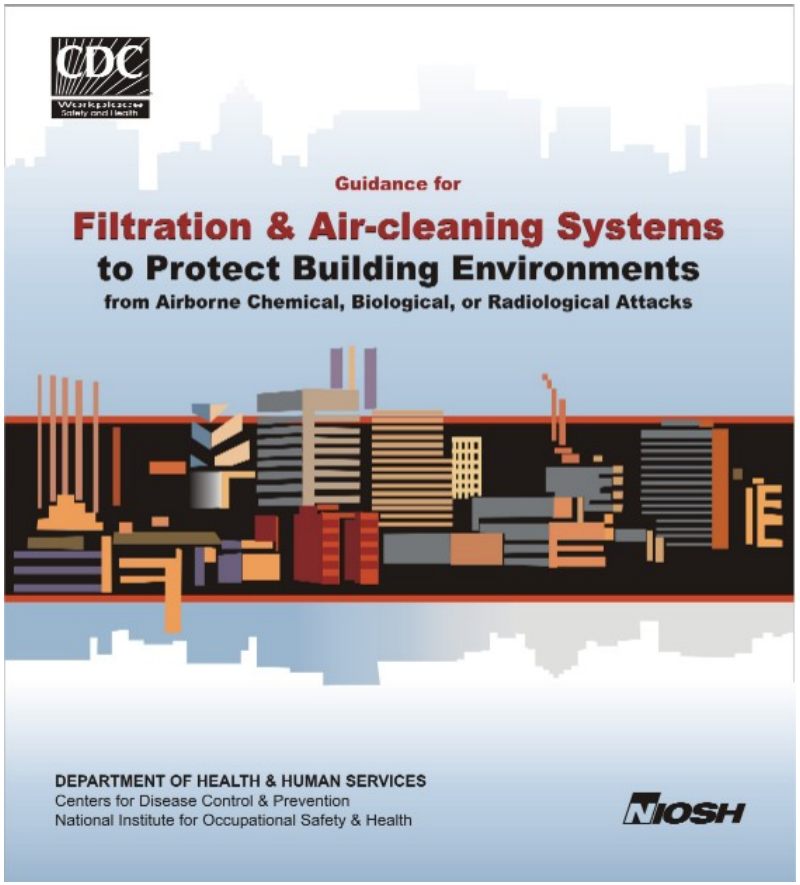
Ventilation Rate Procedure

- Prescriptive ventilation requirements
  - Without quantifying Co or G, assumes Ci is OK if prescribed outdoor airflow is provided
  - Prescribes space (breathing zone) ventilation rates in Table 2
- Most widely used procedure

V_o

Outdoor Air and Extraordinary Circumstances





Dilution of Contaminants

$$C_i = C_o + G/V_o$$

Net* Indoor Generation Rate

Indoor Target Concentration

* Emission - Removal

$$V_o = G/(C_i - C_o)$$

Outdoor Airflow

Outdoor Concentration

outdoor source control

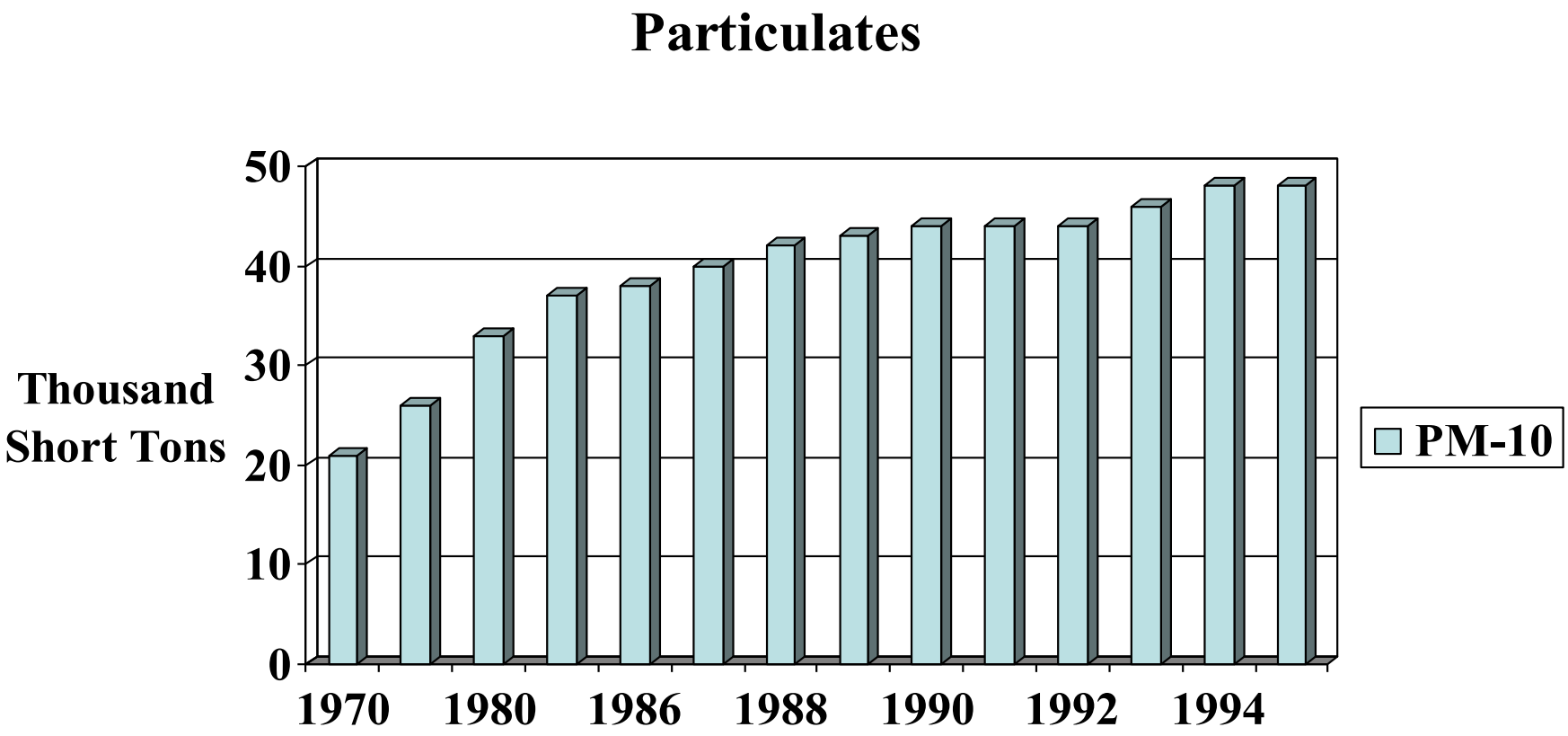
Ambient Air Quality

- Regional outdoor air quality must be evaluated

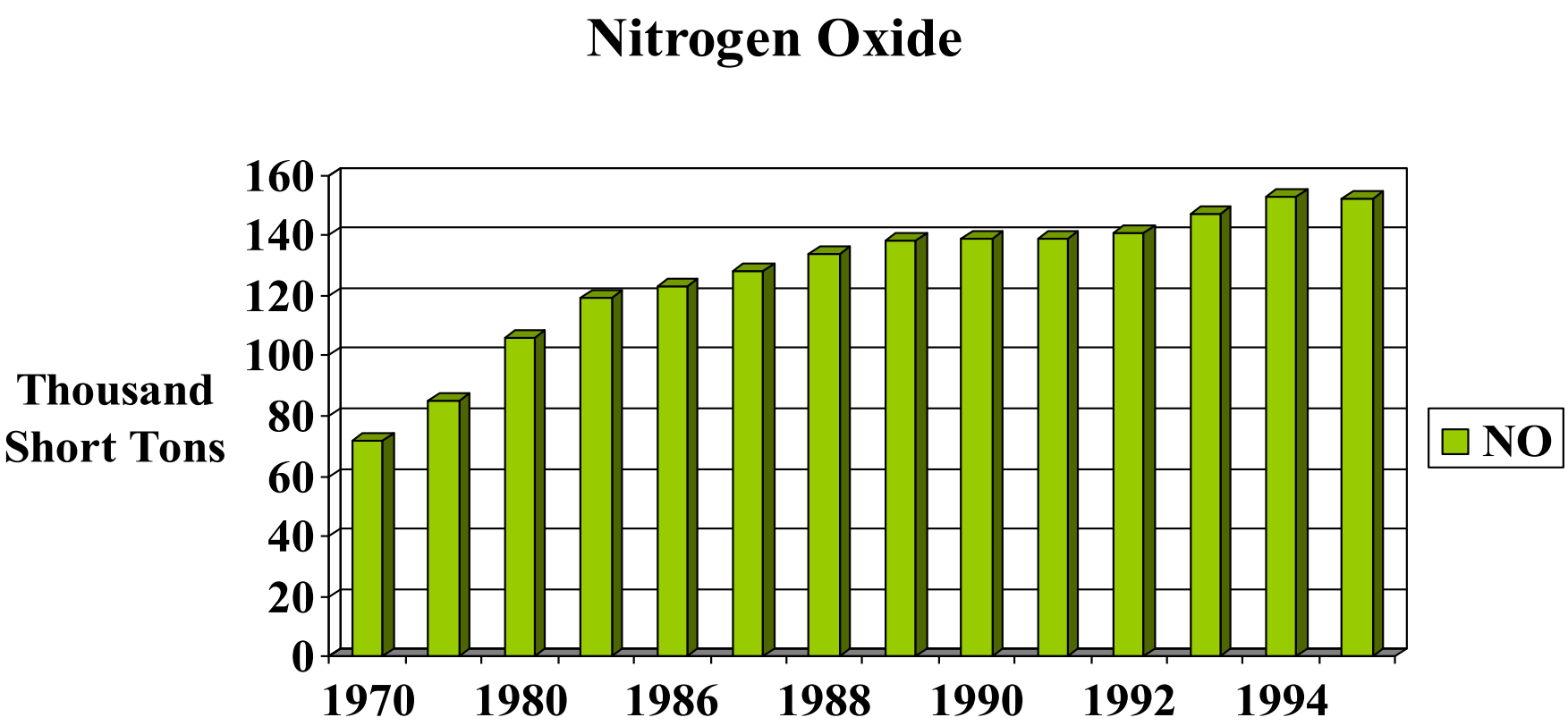
  ASHRAE Std 62-2004: "4.1 Regional Air Quality. *The status of compliance with national ambient air quality standards shall be determined for the geographic area of the building site. In the United States, compliance status shall be either in "attainment" or "non-attainment" with ...NAAQS…"*

C_o

Emission Trends (1970-1995)



Emission Trends (1970-1995)



outdoor source control
Intake Separation

- Should separate intakes from strong outdoor sources
- Minimum separation distance from intake for specific outdoor sources
  - Cooling tower exhaust -- 25 ft
  - Loading dock -- 25 ft

C_o

6.2.1 OUTDOOR AIR TREATMENT

If Outdoor Air is judged to be unacceptable in accordance with Section 4.1 (National Ambient Air Quality Standard), each ventilation system that provides outdoor air through a supply fan shall comply with sections following….

Key excerpts from ASHRAE Standard 62.1

National Primary Ambient Air Quality Standard (US EPA)

Pollutant	*Averaging Period*	*Standard*
Ozone (O_3)	1-hour	0.12 ppm
Carbon Monoxide (CO)	1-hour	9 ppm
	8-hour	35 ppm
Particulate Matter (PM-10)	24-hour	150 $\mu g/m^3$
	Annual arithmetic mean	365 $\mu g/m^3$
Sulfur Dioxide (SO_2)	24-hour	0.14 ppm
	Annual arithmetic mean	0.03 ppm
Nitrogen Dioxide (NO_2)	Annual arithmetic mean	0.53 ppm
Lead (Pb)	Annual arithmetic mean	1.5 $\mu g/m^3$

MERV for Particle Filtration

MERV	Particle Size	Typical Pollutants	Applications	Filter Types
1	>10 µm	Pollen, Dust mites, Sanding dust	Residential, Light commercial	Construction, Throwaway
2				
3				
4				
5	3-10 µm	Dust, Molds, Spores	Commercial, Manufacturing	Pleated, Panel Filters
6				
7				
8				
9	1-3 µm	Legionella, Auto Fumes, Welding Dust	Commercial, Industrial	Bag, Cartridge, Mini-pleat
10				
11				
12				
13	0.1-0.3 µm	Tobacco smoke, Copier toner, Bacteria	Commercial, Medical, Industrial	Bag, Cartridge
14				
15				
16				
17	<0.3 µm	Sea salt, carbon dust, chem-bio, viruses	Clean rooms, Surgery, Isolation	HEPA
18				
19				
20				ULPA



Pleated

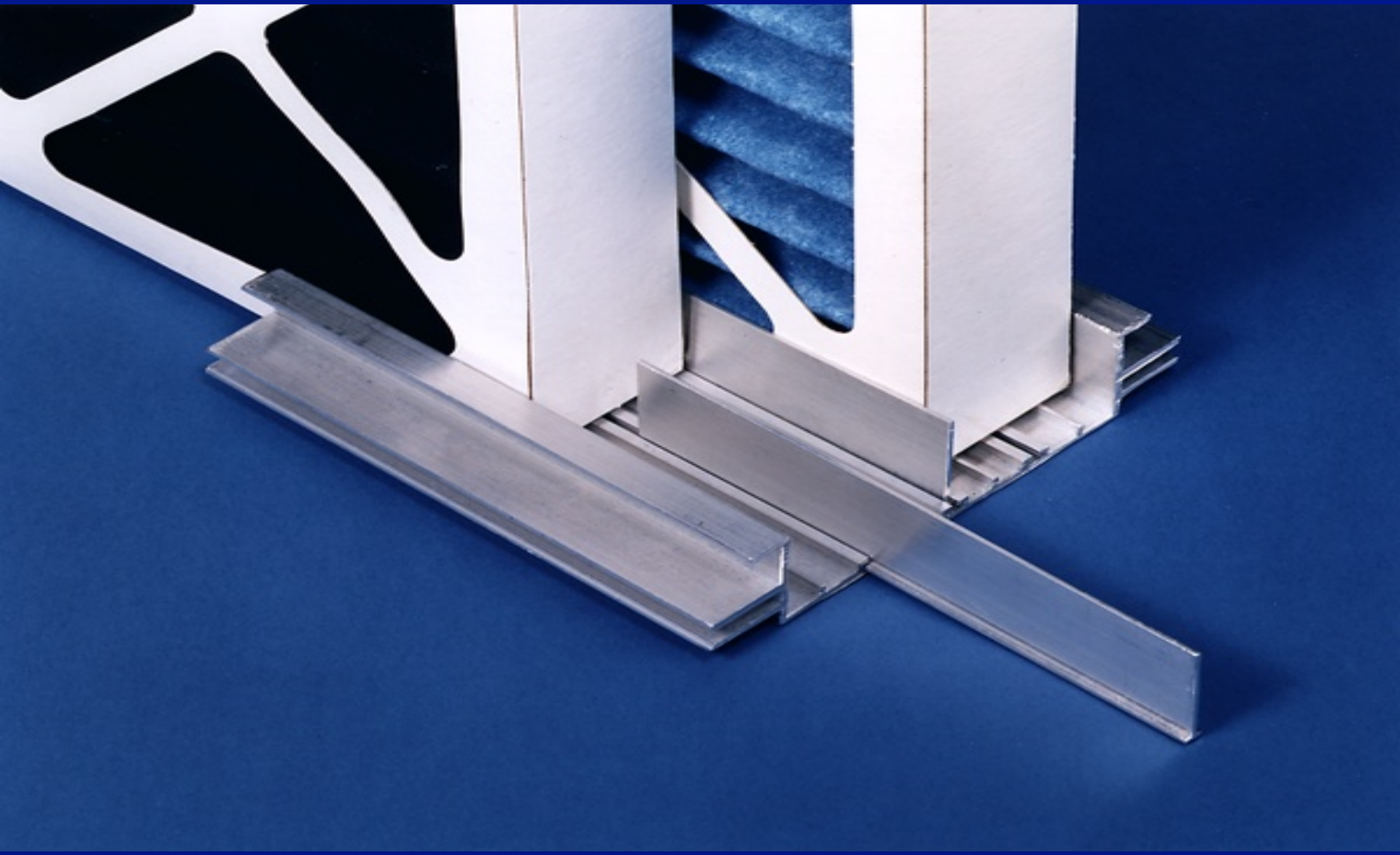


Cartridge



Bag

Gas Filtration



Indoor Air Quality Procedure

- Performance-based requirements
  - Given Ci target, Co and G values, and find Vo
  - Lists limits for 10 contaminants, but open-ended list
  - Requires a subjective analysis for odors
  - Describes the use of air cleaning to reduce OA rates

$$V_o$$

ANSI/ASHRAE Standard 62.1-2010

Ventilation for Acceptable Indoor Air Quality

- Ventilation Rate Procedure (VRP)
  - Conventional prescriptive design approach
  - OA rate determined by space type, occupancy level & floor area
- Indoor Air Quality Procedure (IAQP)
  - Performance based design approach
  - OA & other design parameters determined from an analysis of contaminant sources, concentration & perceived acceptability target levels
- Natural Ventilation Procedure (NVP)
  - Prescriptive design procedure for natural ventilated zones.

IAQP Design Approach

OA flow rates shall be the larger of those determined with

- Mass balance analysis and

either with

- Subjective evaluation or
- Similar zone

Combination of IAQP & VRP

- IAQP to address the control of the specific contaminants
- VRP to address the general aspects of indoor air quality of the design space

Mass Balance Analysis

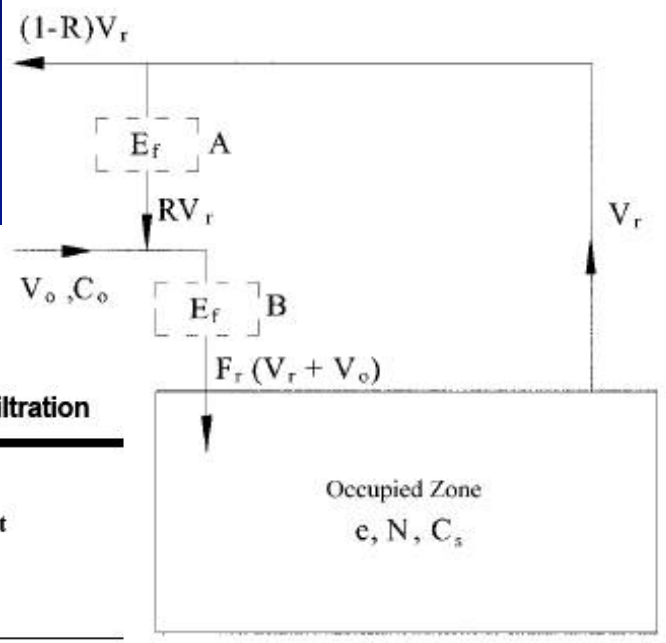


TABLE D-1 Required Outdoor Air or Space Contaminant Concentration with Recirculation and Filtration

Filter Location	Required Recirculation Rate: Flow	Required Recirculation Rate: Outdoor Airflow	Required Outdoor Airflow	Space Contaminant Concentration
None	VAV	100%	$V_o = \frac{N}{E_v F_r (C_s - C_o)}$	$C_s = C_o + \frac{N}{E_v F_r V_o}$
A	Constant	Constant	$V_o = \frac{N - E_v R V_r E_f C_s}{E_v (C_s - C_o)}$	$C_s = \frac{N + E_v V_o C_o}{E_v (V_o + R V_r E_f)}$
A	VAV	Constant	$V_o = \frac{N - E_v F_r R V_r E_f C_s}{E_v (C_s - C_o)}$	$C_s = \frac{N + E_v V_o C_o}{E_v (V_o + F_r R V_r E_f)}$
A	VAV	Proportional*	$V_o = \frac{N - E_v F_r R V_r E_f C_s}{E_v F_r (C_s - C_o)}$	$C_s = \frac{N + E_v F_r V_o C_o}{F_r E_v (V_o + R V_r E_f)}$
B	Constant	Constant	$V_o = \frac{N - E_v R V_r E_f C_s}{E_v [C_s - (1 - E_f) C_o]}$	$C_s = \frac{N + E_v V_o (1 - E_f) C_o}{E_v (V_o + R V_r E_f)}$
B	VAV	100%	$V_o = \frac{N}{e F_r [C_s - (1 - E_f) C_o]}$	$C_s = \frac{N + e F_r V_o (1 - E_f) C_o}{e F_r V_o}$
B	VAV	Constant	$V_o = \frac{N - E_v F_r R V_r E_f C_s}{E_v [C_s - (1 - E_f) C_o]}$	$C_s = \frac{N + E_v V_o (1 - E_f) C_o}{E_v (V_o + F_r R V_r E_f)}$
B	VAV	Proportional	$V_o = \frac{N - E_v F_r R V_r E_f C_s}{E_v F_r [C_s - (1 - E_f)(C_o)]}$	$C_s = \frac{N + E_v F_r V_o (1 - E_f) C_o}{E_v F_r (V_o + R V_r E_f)}$

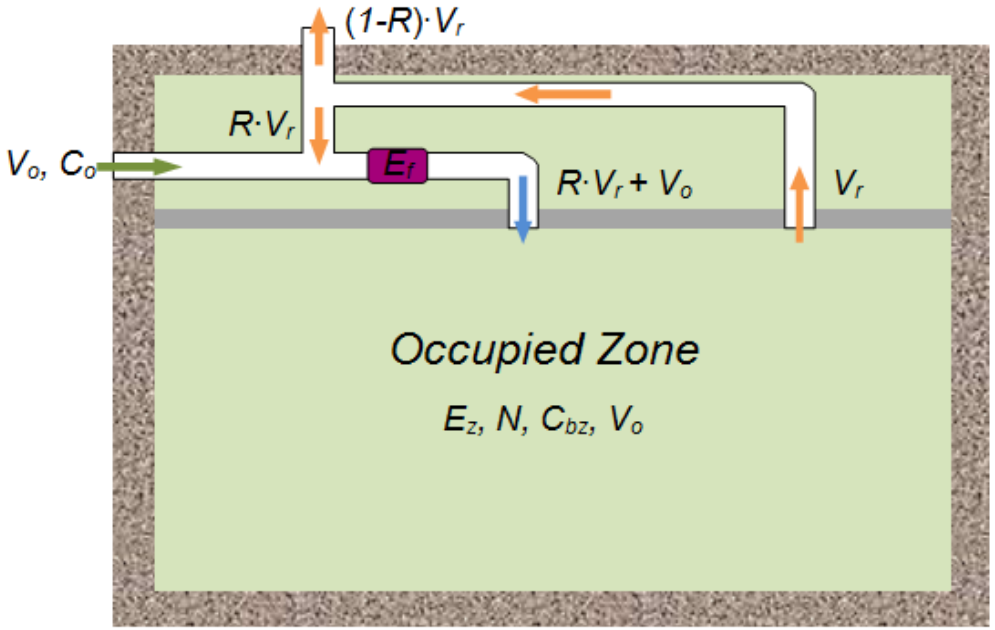
⇐ Example

IAQP Example of Green Office

Mass balance analysis - 3 cases of ventilation designs

ASHRAE 62.1 IAQP	5 cfm/person X 80 people	400 cfm OA
ASHRAE 62.1 VRP	(5 cfm/person X 80 people) + (0.06 cfm/ft^2 X 10,000 ft^2)	1000 cfm OA
LEED EQc2	1.3 X (1000 cfm)	1300 cfm OA

$$C_{bz} = \frac{N + E_z V_o \left(1 - E_f\right) \cdot C_o}{E_z \left(V_o + R V_r E_f\right)}$$



For VRP and LEED cases, Ef = 0

Building Codes & Standards

ASHRAE Standard 90.1 <Section 6.5.6.1>

Energy Standard For Buildings Except Low Rise Residential Buildings

A standard to provide minimum requirements for the energy-efficient design of buildings

When: SA ≥ 5000 cfm
and
OA ≥ 70% of SA

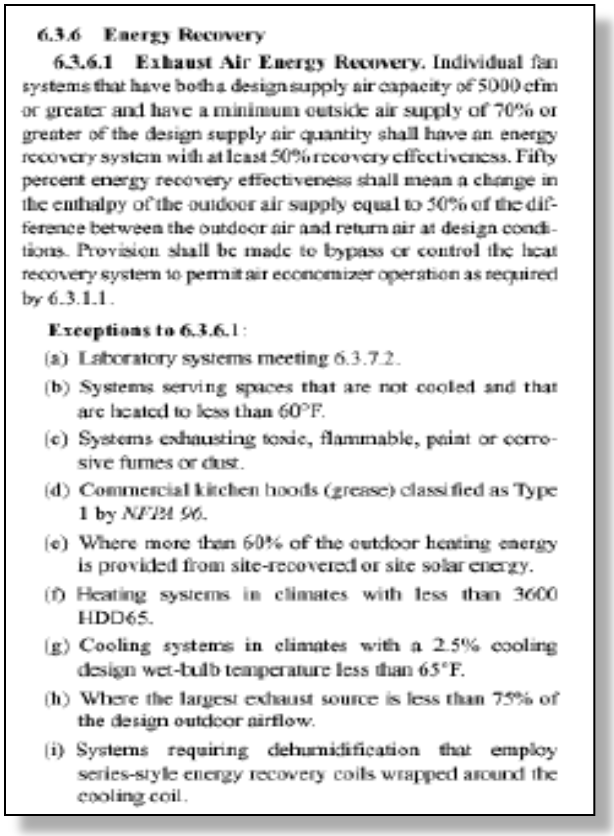
Then: E min ≥ 50%
Minimum Effectiveness
for total energy recovery
Enthalpy (latent +sensible)

Exception: EA ≤ 75% of OA



Laboratory exhausts
Fume exhausts including kitchen exhausts Std 62.1-2007 allows its use with class 1-3 air

Pertinent Excerpt from 90.1



6.3.6 Energy Recovery

6.3.6.1 Exhaust Air Energy Recovery. Individual fan systems that have both a design supply air capacity of 5000 cfm or greater and have a minimum outside air supply of 70% or greater of the design supply air quantity shall have an energy recovery system with at least 50% recovery effectiveness. Fifty percent energy recovery effectiveness shall mean a change in the enthalpy of the outdoor air supply equal to 50% of the difference between the outdoor air and return air at design conditions. Provision shall be made to bypass or control the heat recovery system to permit air economizer operation as required by 6.3.1.1.

Exceptions to 6.3.6.1:

(a) Laboratory systems meeting 6.3.7.2.

(b) Systems serving spaces that are not cooled and that are heated to less than 60°F.

(c) Systems exhausting toxic, flammable, paint or corrosive fumes or dust.

(d) Commercial kitchen hoods (grease) classified as Type 1 by *NFPA 96*.

(e) Where more than 60% of the outdoor heating energy is provided from site-recovered or site solar energy.

(f) Heating systems in climates with less than 3600 HDD65.

(g) Cooling systems in climates with a 2.5% cooling design wet-bulb temperature less than 65°F.

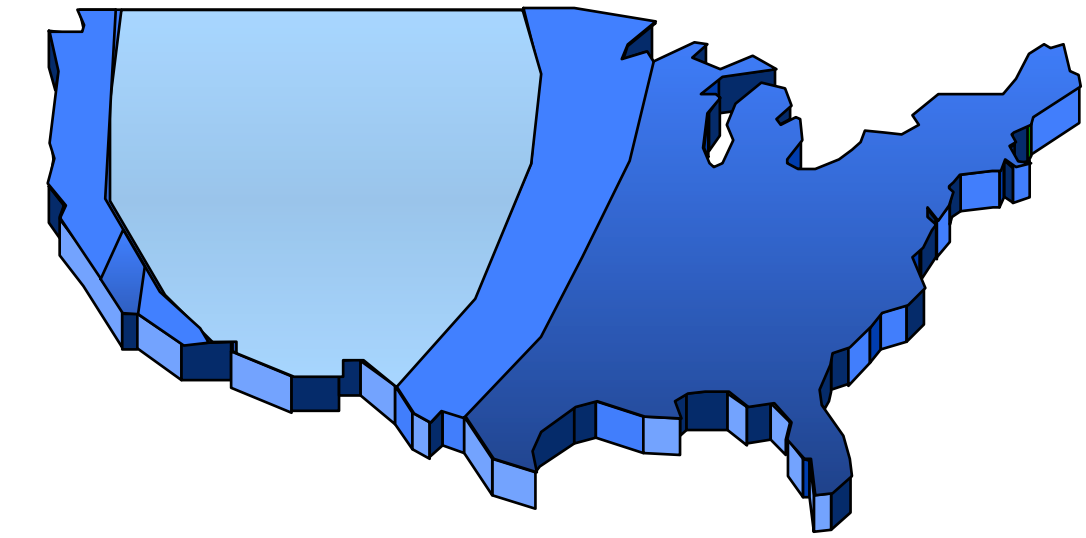
(h) Where the largest exhaust source is less than 75% of the design outdoor airflow.

(i) Systems requiring dehumidification that employ series-style energy recovery coils wrapped around the cooling coil.

6.3.6.1 Exhaust Air Energy Recovery

Individual fan systems that have…a design supply air capacity of 5000-CFM or greater and have a minimum outside air supply of 70% or greater…shall have an energy recovery system with at least 50% recovery effectiveness….[which] shall mean a change in the enthalpy of the…supply equal to 50% of the difference between the outdoor air and return air at design conditions.

Ventilation Load Index (VLI)



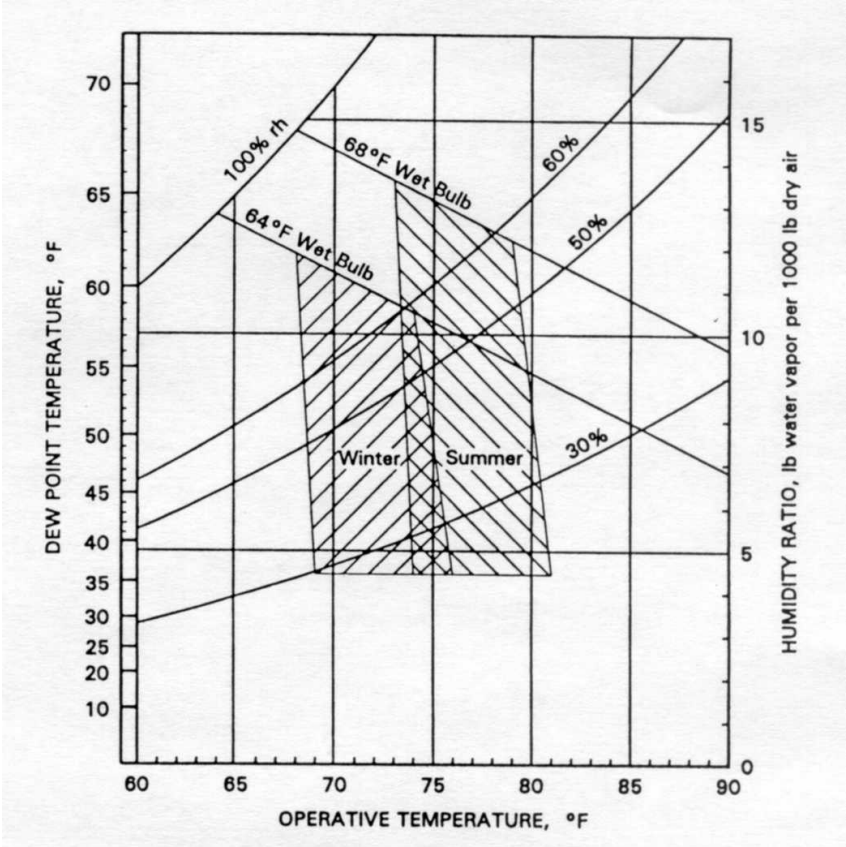
High Latent to Sensible Ratio

Medium Latent to Sensible Ratio

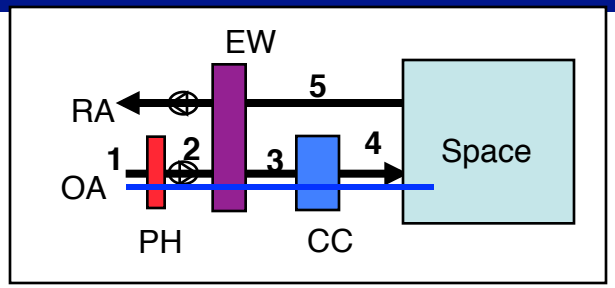
Low Latent to Sensible Ratio

Human Comfort Zones

ASHRAE Summer and Winter Comfort Zones (Acceptable Ranges of Operative Temperature and Humidity for People in Typical Summer and Winter Clothing During Primarily Sedentary Activity).



Typical Psychrometrics



Hot & humid OA condition

Enthalpy Wheel in DOAS

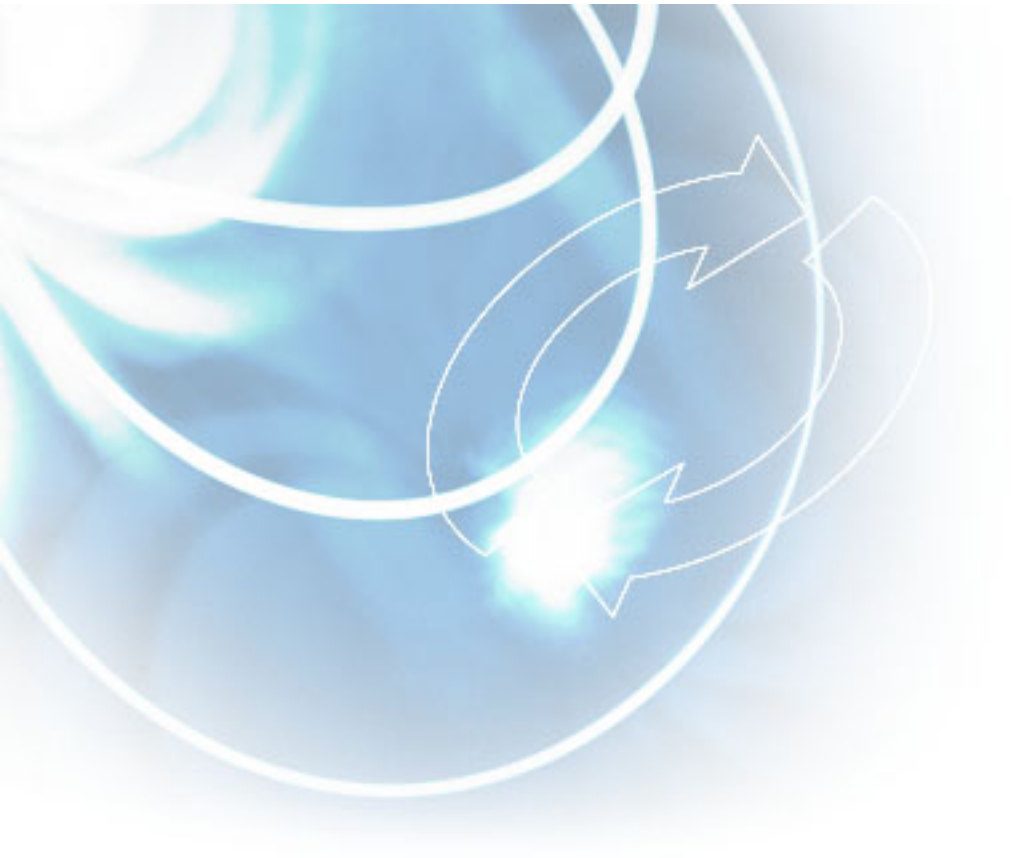
- A significant reduction in the design OA cooling load, reducing both the chiller size & the peak demand
- A reduction in the annual OA cooling and dehumidify energy consumption
- A significant reduction in the OA heating and humidification energy consumption (in the North)
- Conforms to ASHRAE Standard 90.1-2007
- A major reduction in the variability of the OA conditions entering the CC.

Application Categories

- **Comfort-to-Comfort**
  - *(Standard HVAC Applications)*
- Process-to-Comfort
  - *(Light Industrial Applications)*
- Process-to-Process
  - *(Heavy Industrial Applications)*



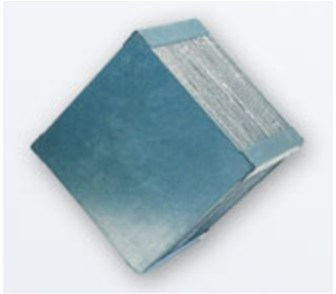
Survey of Existing Technologies



- Thermosiphon
- **Heat Pipe Heat Exchanger**
- **Fixed-Plate Heat Exchanger**
- **Rotary Wheel**
- Coil Recovery Systems (Runaround Loop)

Energy Recovery Solutions in DOAS

- Heat Pipe Heat Exchangers
- Fixed Plate Heat Exchangers
- Rotary Air-to-Air Heat Exchangers







Passive vs. Active Energy Recovery

Passive Systems	Active Systems
No external energy source is required for heat transfer to take place.	Continuous external energy input is required for heat transfer to take place.

DOAS + Energy Recovery





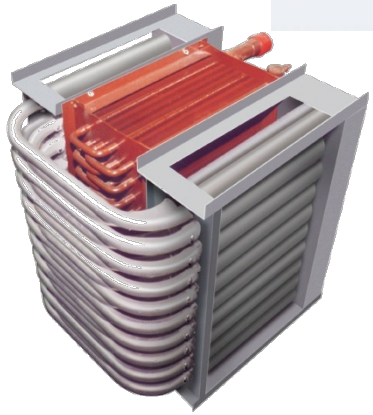


Passive vs. Active Energy Recovery

Passive Systems	Active Systems
▪ Thermosiphon ▪ **Heat Pipe** ▪ **Fixed-Plate** ▪ **Rotary Wheel**	▪ **Rotary Wheel** ▪ Coil Recovery Systems (Runaround Loop)

Heat Pipe Heat Exchanger





Advantages:

- 0% Cross Contamination
- Size Flexibility
- Ideal for Retrofit

Considerations:

- Low Sensible Effectiveness (45 to 55%)
- Installation Sensitivity
- Higher Cost

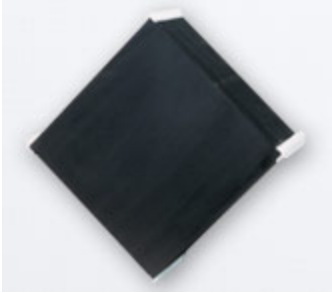
Fixed Plate Heat Exchanger

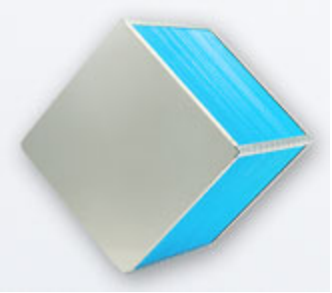
Advantages:

- High sensible effectiveness (60 to 70%)
- Durable construction
- Low maintenance
- Cross-flow HX provides best price-to-performance (and performance-to-pressure drop) ratio

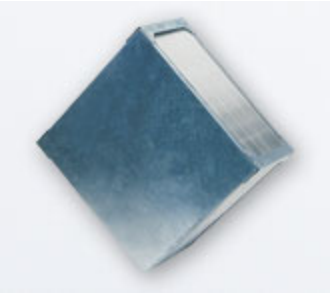
Considerations:

- High pressure drop associated with counter-flow heat exchangers
- Higher cost associated with counter-flow heat exchangers
- AHU layout



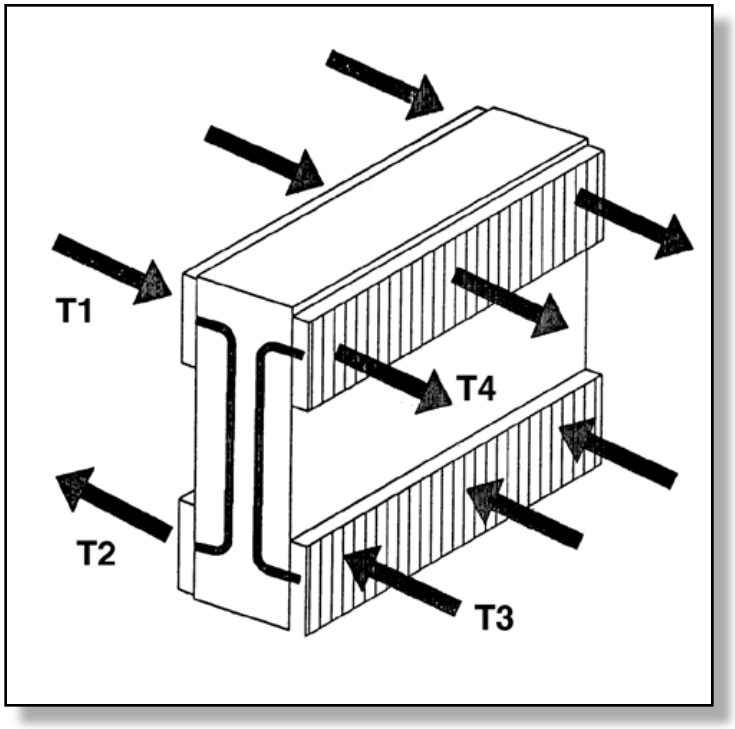






Theory of Operation





Rotary Heat Exchanger

Advantages:

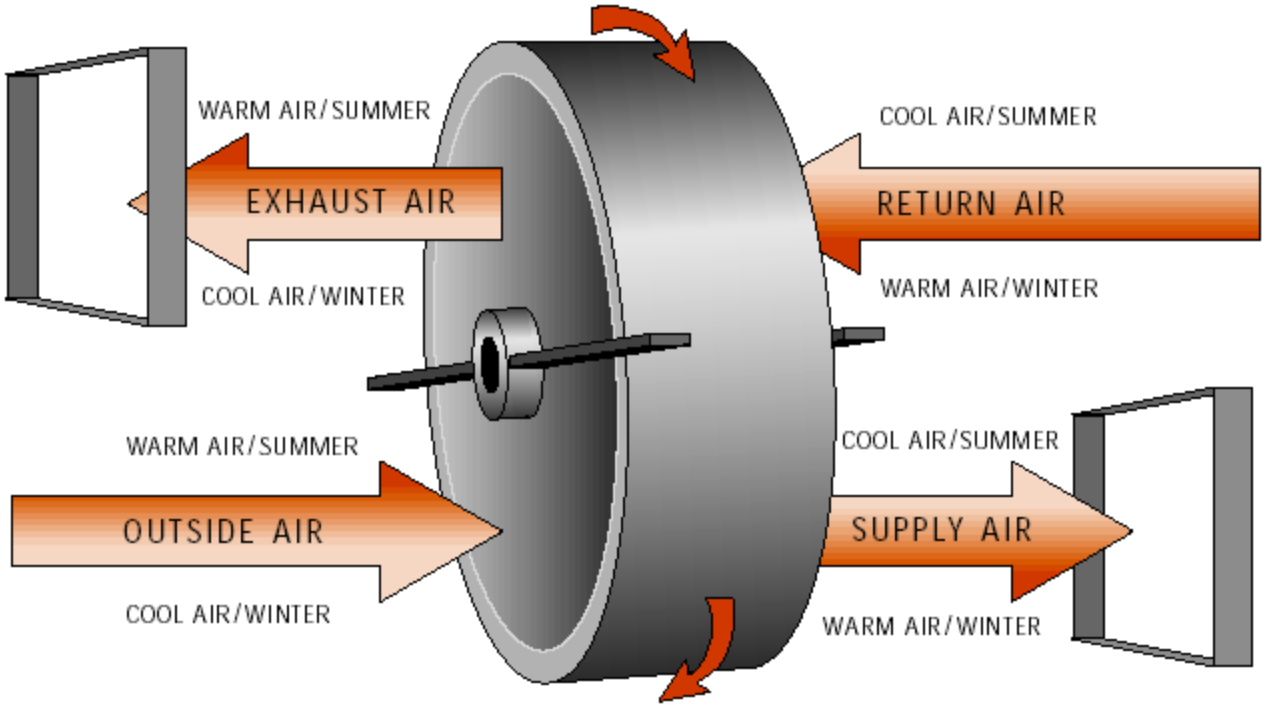
- High **total** effectiveness (75% to 80%)
- Self-cleaning effect
- Available as sensible or enthalpy device
- Low pressure drop, low maintenance and low carry-over with proper enthalpy wheel supplier

Considerations:

- Possibility of carry-over for critical applications



Theory of Operation



Passive vs. Active Wheels

Passive Wheel

- Energy recovery / energy transfer is the primary objective
- Comfort-to-comfort application
- No regeneration heat is required

Active Wheel

- Humidity control is the primary objective (typically low-dew-point desiccant dehumidification)
- Regeneration heat is always required

Silica Gel vs. Molecular Sieve

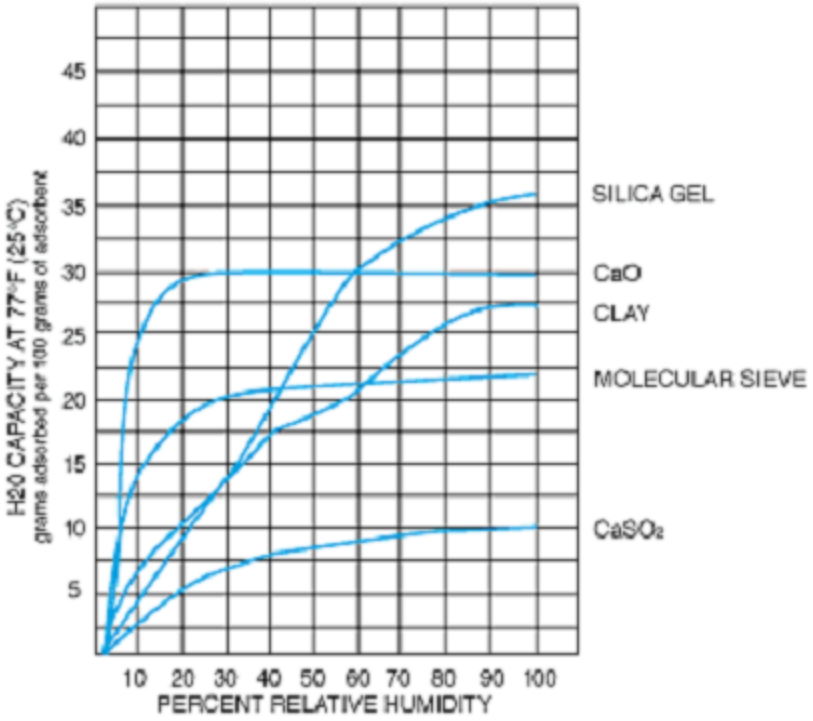
Silica Gel

- Wide pore structure
- Affinity for water vapor
- Low retentivity (weak Van der Waals bonds)
- Optimal operating range found in typical HVAC applications

Molecular Sieve

- Typically 3A to 4A
- High retentivity (very strong bond)
- Without regeneration heat a layer of water vapor is always present on the surface of the exchanger
- Optimal operating range under low humidity

Silica Gel vs. Molecular Sieve





Engineering Evaluation

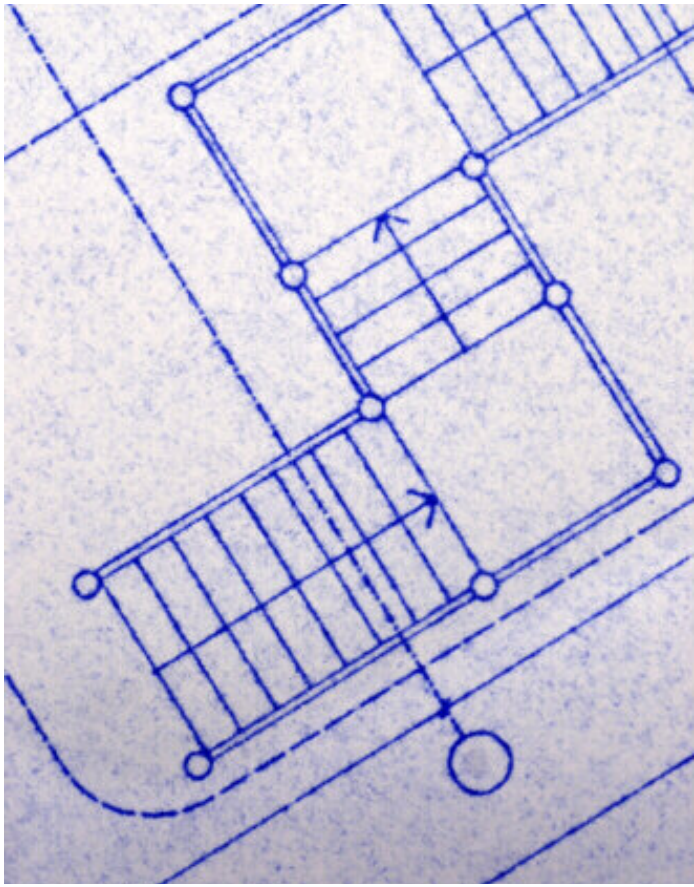


- Passive vs. Active Systems
- Carry Over or Cross-Contamination
- Sensible vs. Total Energy Recovery
- Pressure Drop
- Frost Control Strategies
- Thermodynamic Performance Requirements
- Life Cycle Cost / Operational Control

General Frost Control Strategies

- Face and Bypass
- Preheat Frost Control
- Exhaust Only Defrost
- Recirculation Defrost
- On/Off

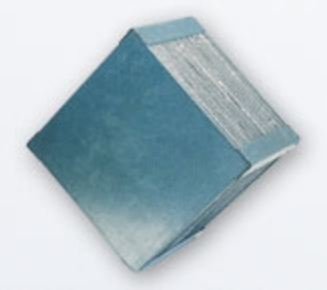
} Not Recommended



Technology Specific Strategies



- Tilt Control



- Traversing Defrost
- Cold Corner Defrost



- Speed Control (VFD/VSD)

THERMODYNAMIC EVALUATION

Nominal Airflow: 5000-CFM

Heat Exchanger Design Velocity: 450 FPM

ARI Design Conditions*:

Summer

OA Temp.: 95°F db / 78°F wb

RA Temp.: 75°F db / 63°F wb

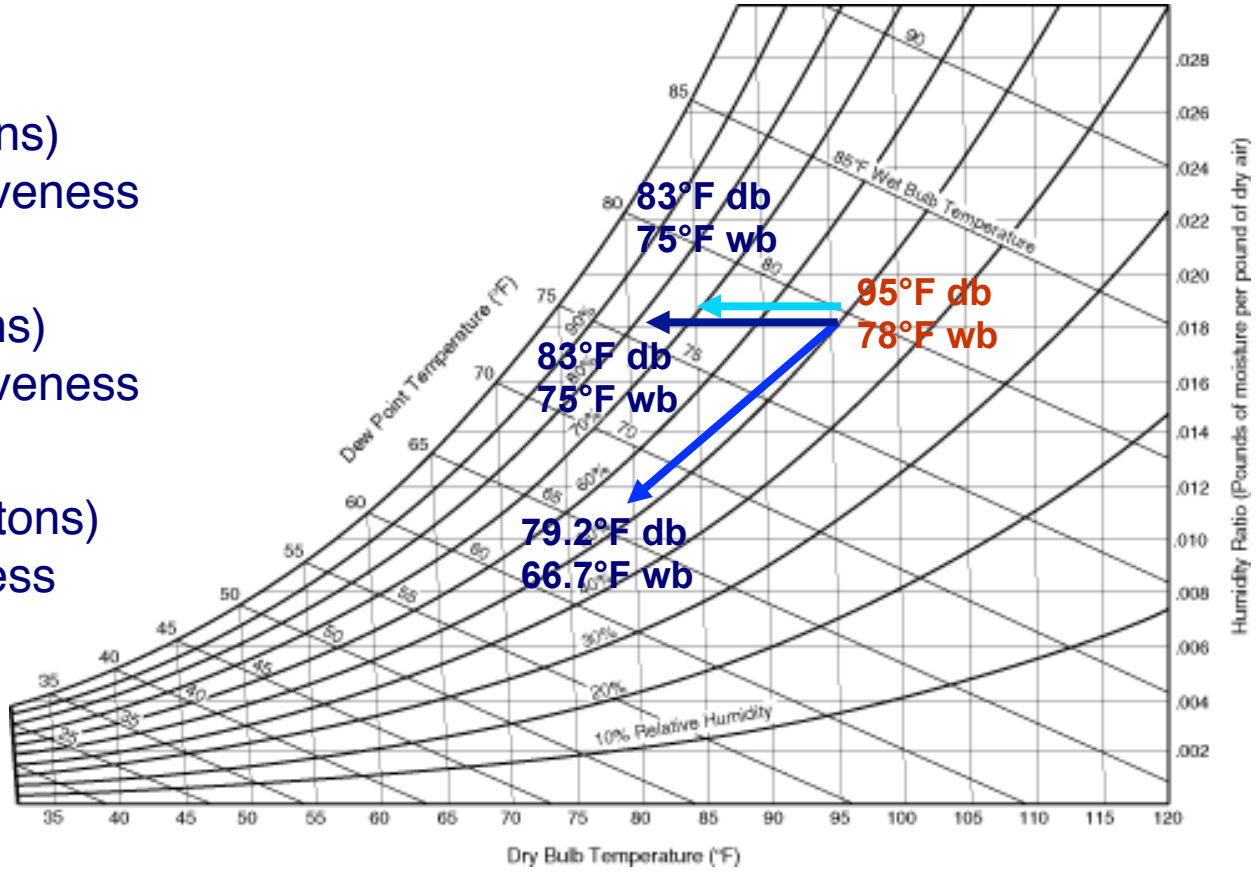
Winter

OA Temp.: 35°F db / 33°F wb

RA Temp.: 70°F db / 58°F wb

Heat Exchanger Performance Comparison

- Heat Pipe
  53,935 btu/hr (4.5 tons)
  50% Sensible Effectiveness
- Fixed Plate
  65,903 btu/hr (5.5 tons)
  60% Sensible Effectiveness
- Enthalpy Wheel
  149,000 btu/hr (12.4 tons)
  79% Total Effectiveness



Outdoor Air Systems Design



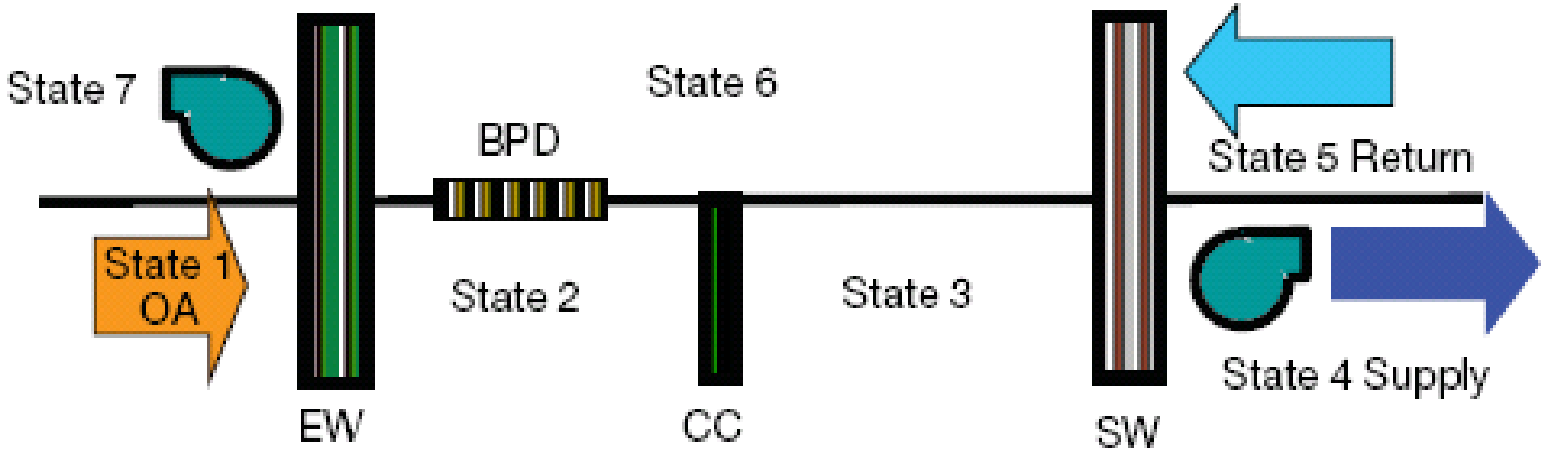
Design Objectives ➡ Human Comfort

Depends on:

- Geographic Location
- Application Requirements
- Appropriate Levels of Temperature and Humidity

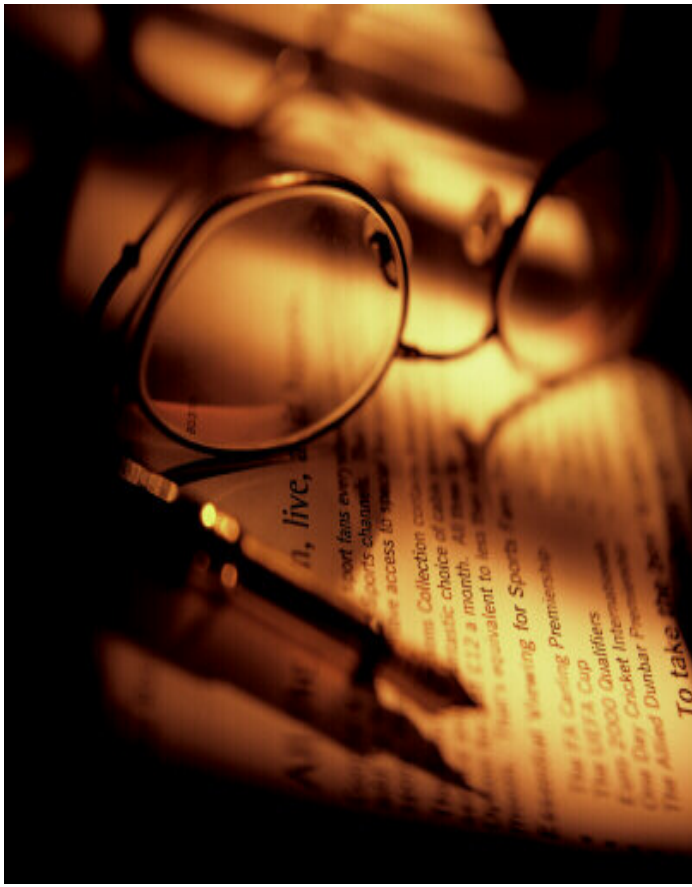
Outdoor Air Systems Design

SW	EW	CC	PDHC	HC	BPD	ADesW
Sensible wheel	Enthalpy wheel	Cooling coil	Passive dehumidification component	Heating coil	Bypass damper	Active desiccant wheel



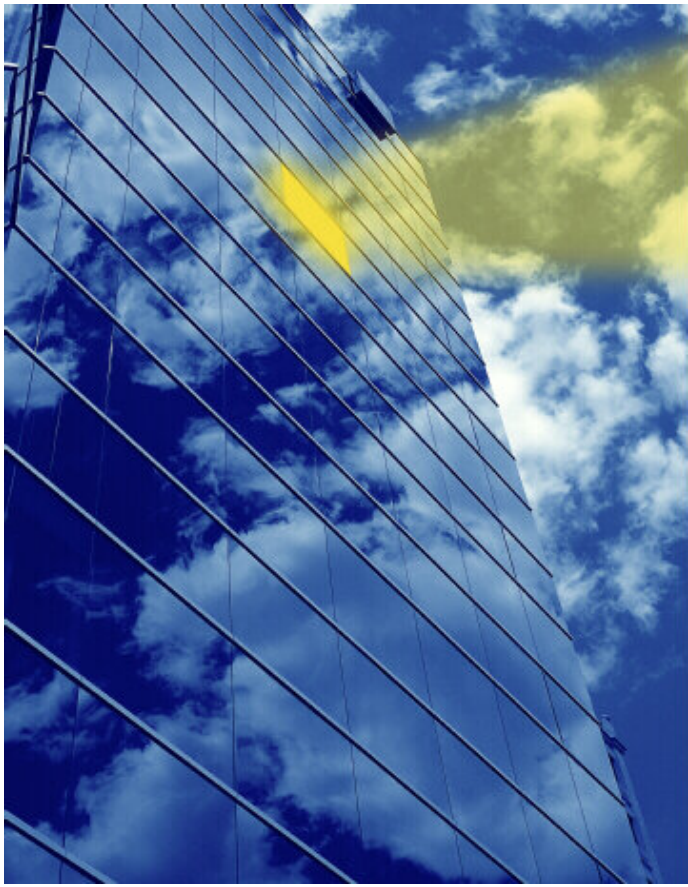
Energy Recovery Systems

- Standard ERVs/HRVs
- Packaged Recovery Systems
- **Neutral Air Systems and Dedicated Outdoor Air Systems (DOAS)**
- Partial Outdoor Air Applications
- Custom Recovery Systems

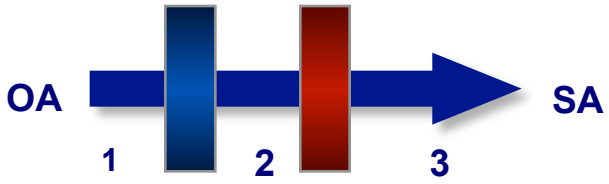


Energy Recovery Design Examples

- Energy Recovery Pre-Cooler Re-Heater (Wrap Around)
- Sensible Energy Recovery
- Enthalpy Recovery
- Passive / Active Desiccant
- Total + Sensible Recovery

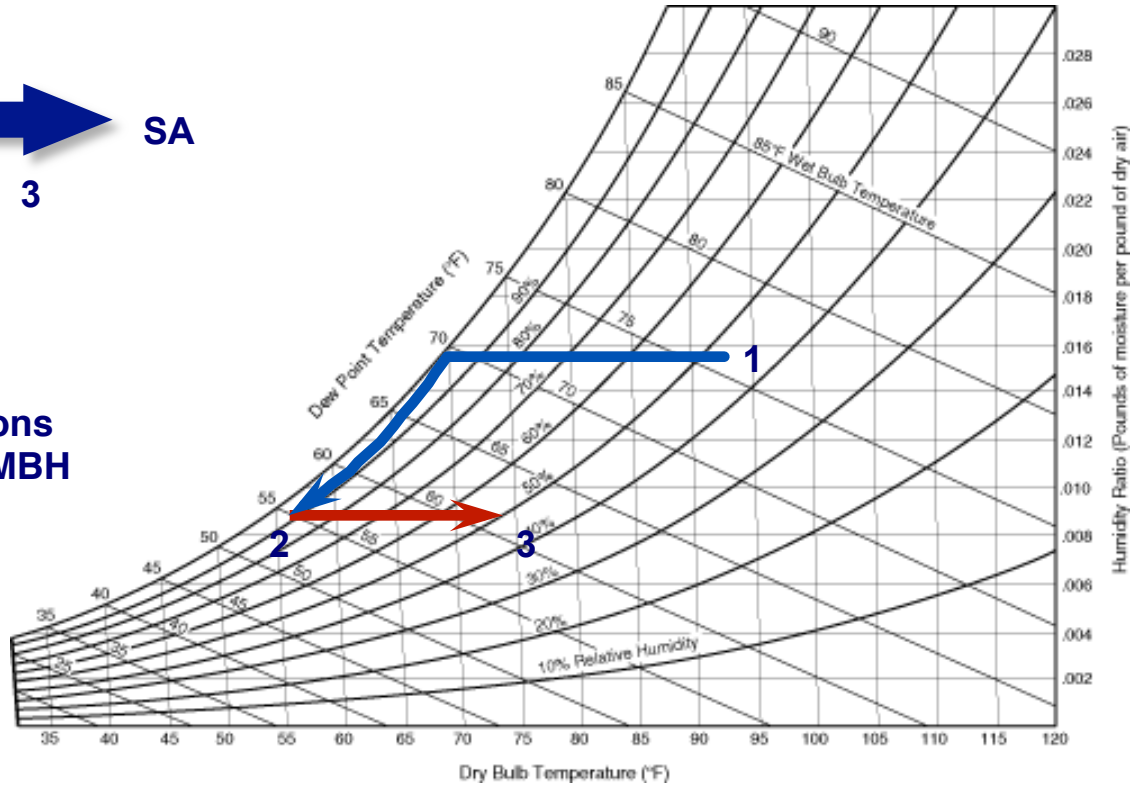


100% Outside Air Conditioning

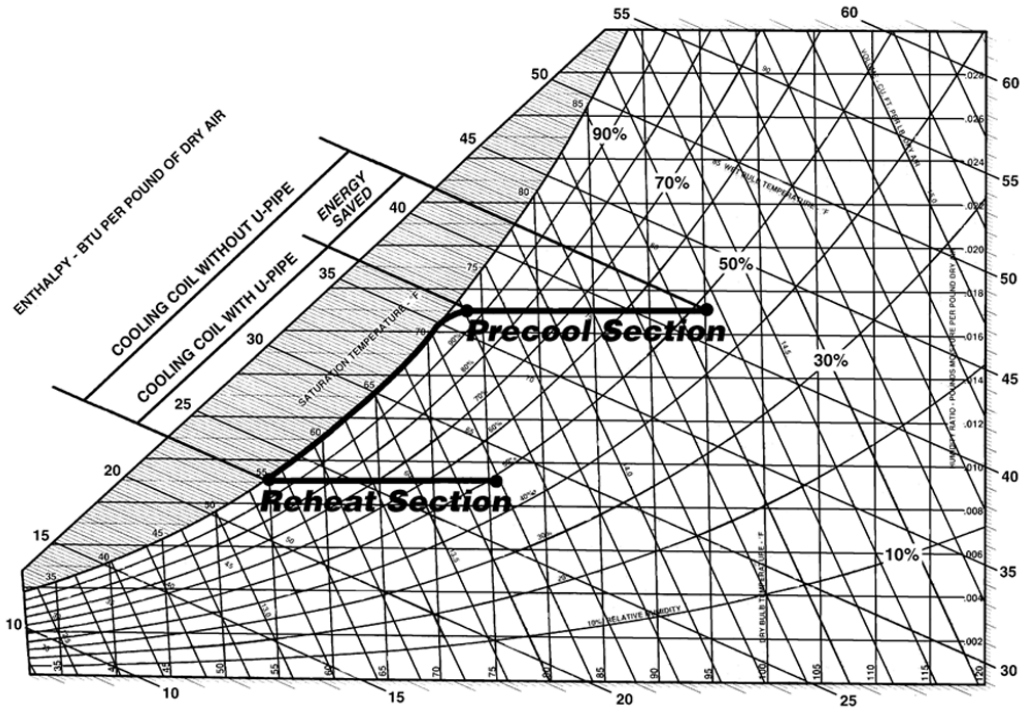


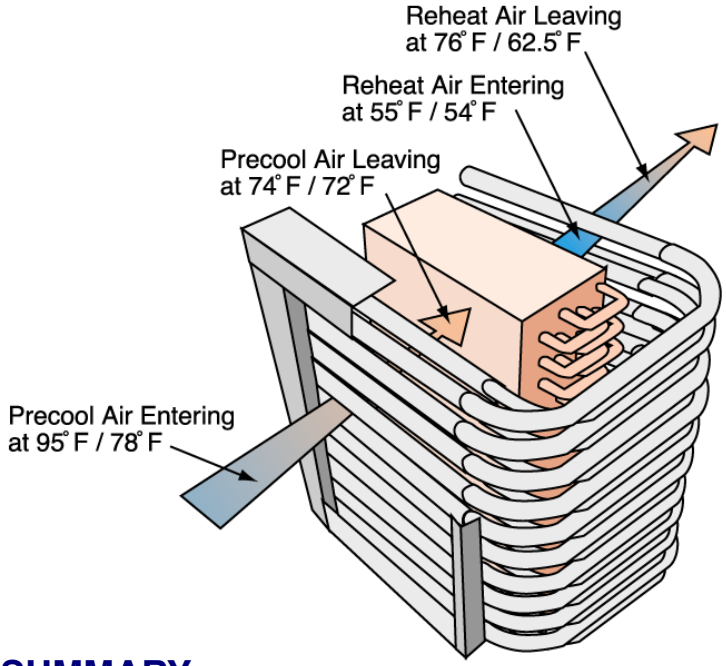
SUMMARY

Cooling Required: 67 Tons
Heating Required: 215 MBH



Energy Recovery Pre-Cooler Re-Heater

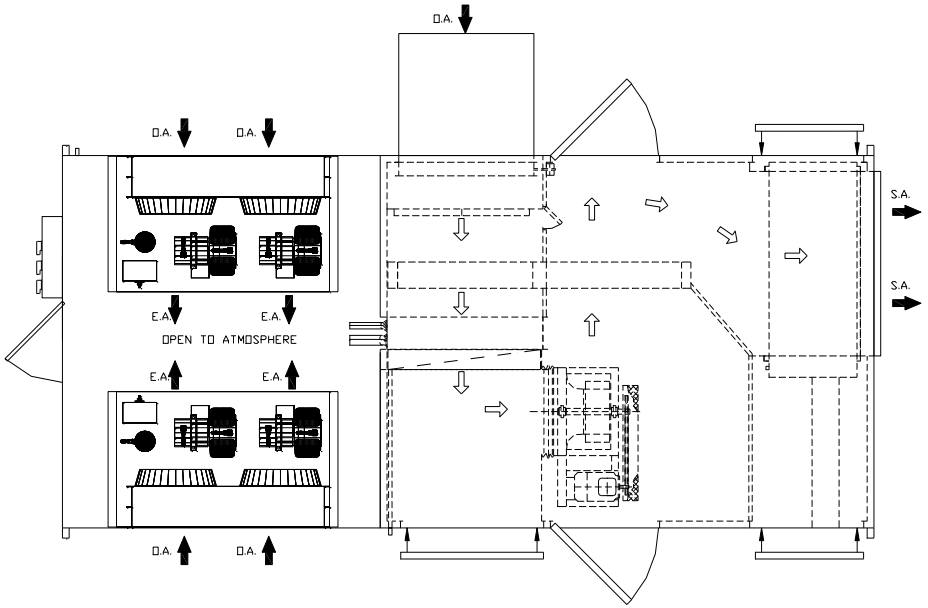


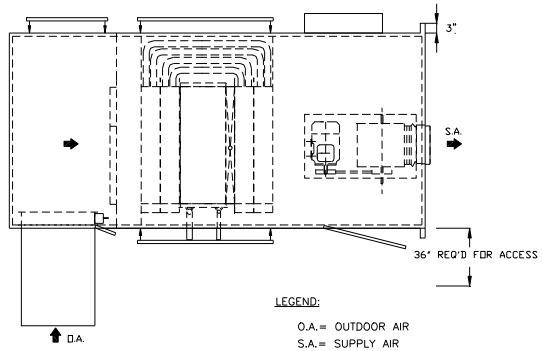


SUMMARY

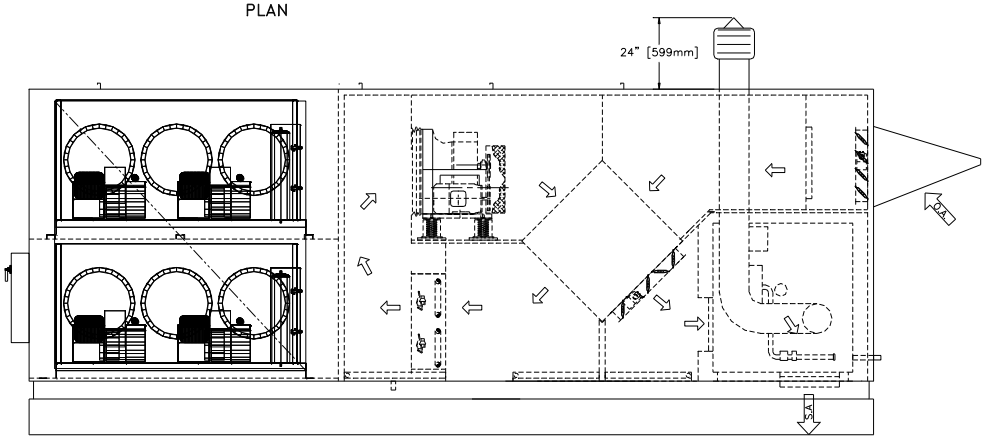
Cooling Required: 47 Tons
Heating Required: None

Typical Arrangements

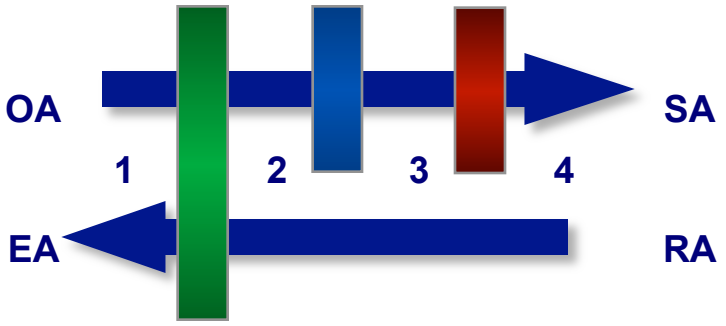




PLAN

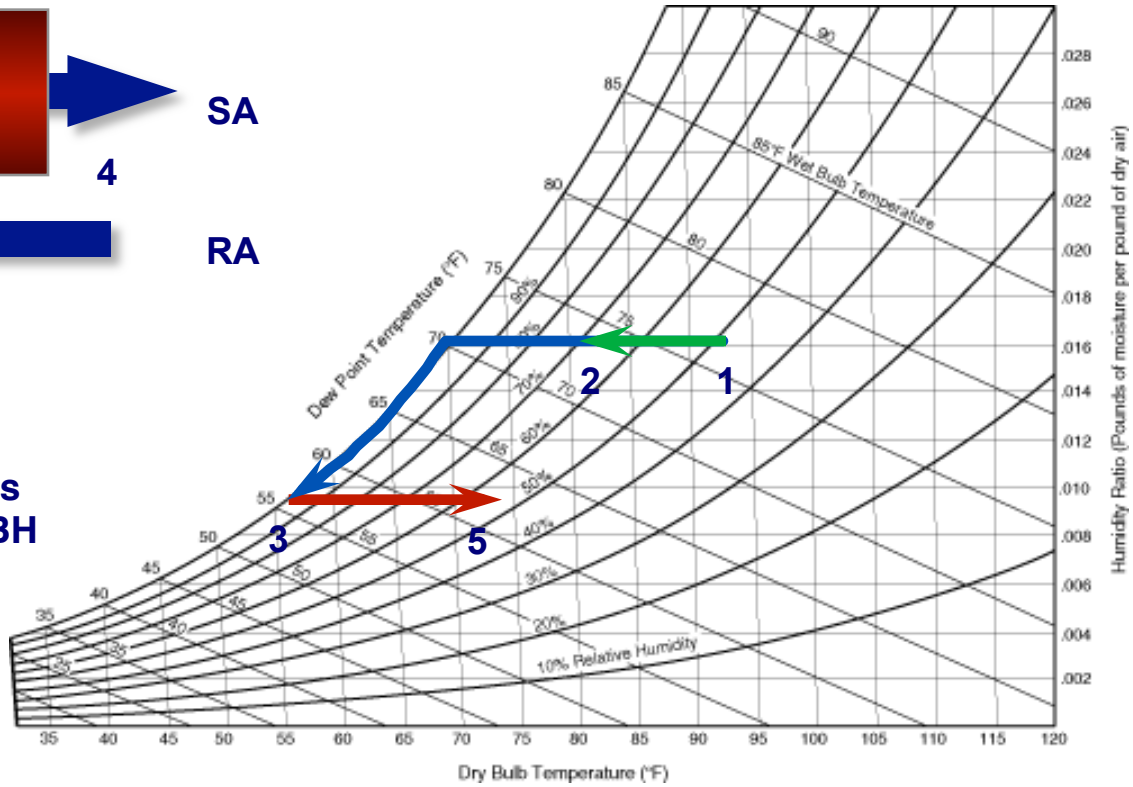


Sensible Heat Recovery

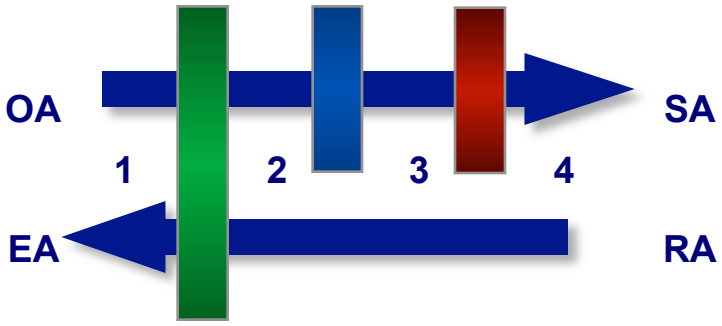


SUMMARY

Cooling Required: 53 Tons
Heating Required: 215 MBH

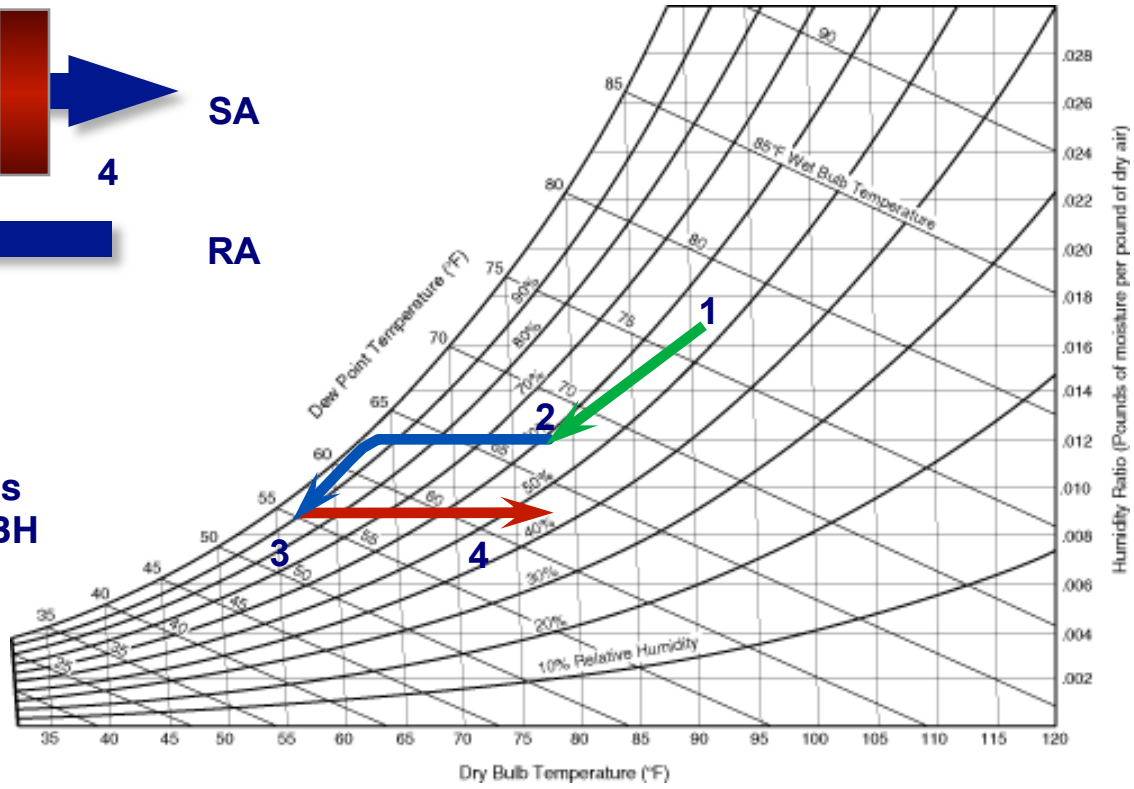


Total Heat Recovery

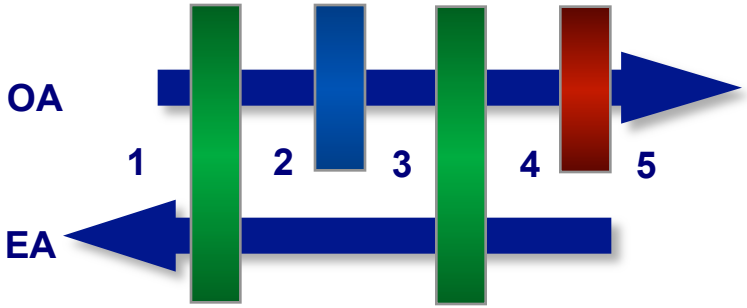


SUMMARY

Cooling Required: 31 Tons
Heating Required: 215 MBH

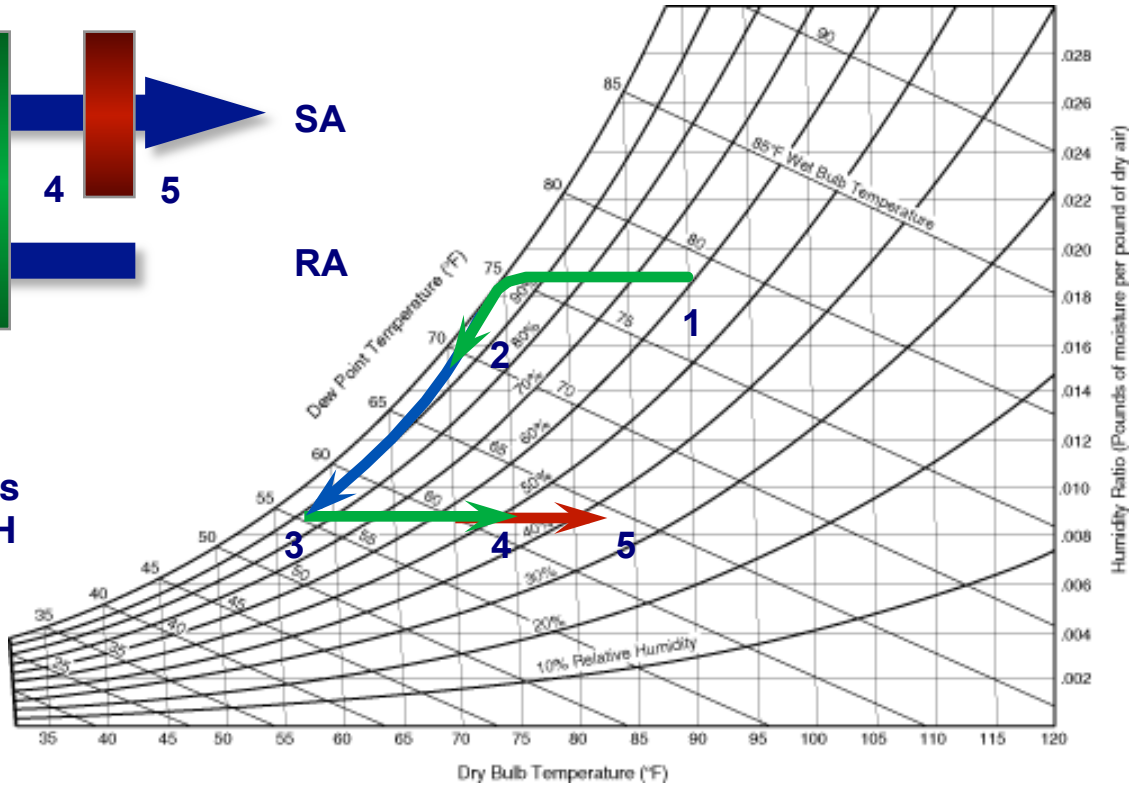


Dual Sensible Recovery



SUMMARY

Cooling Required: 47 Tons
Heating Required: 75 MBH

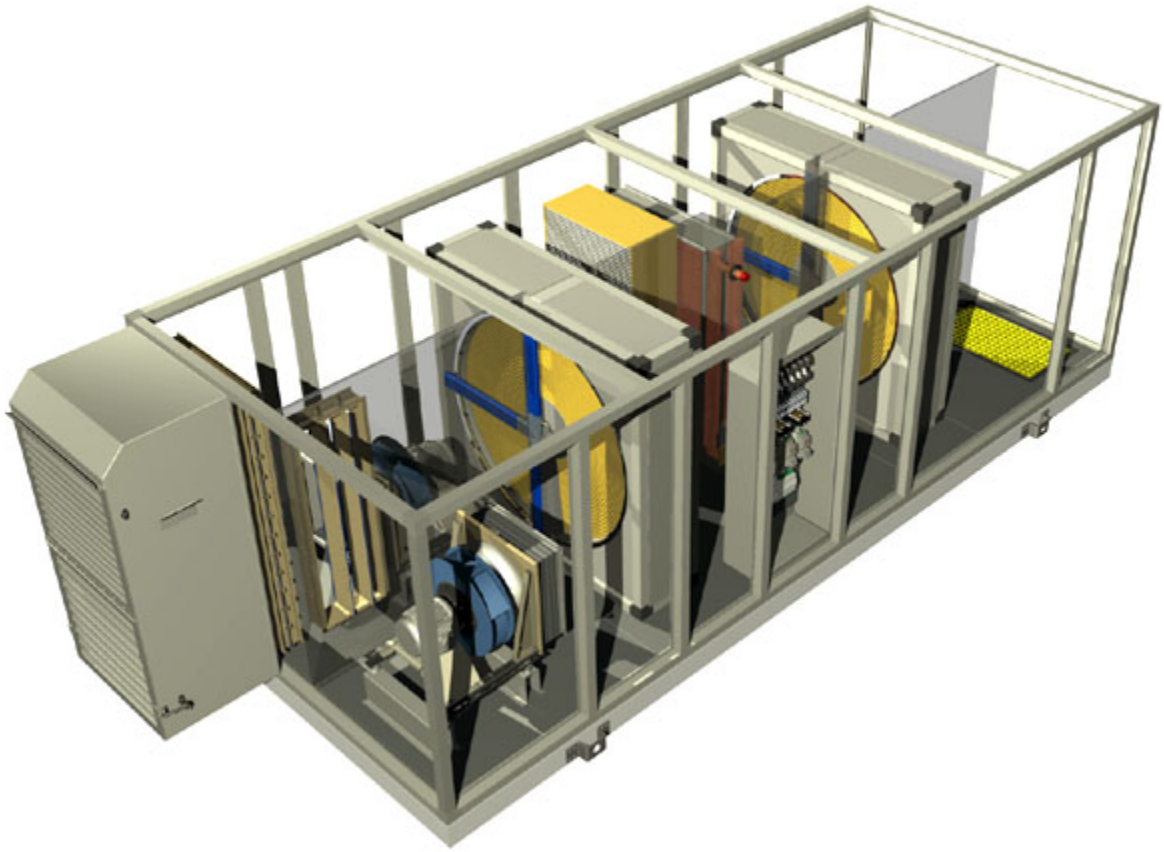


Energy Recovery Units

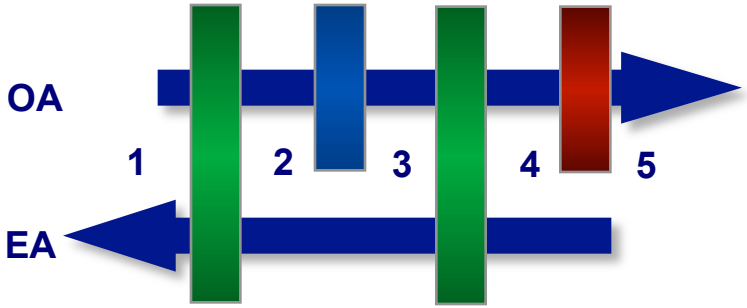
Dual Device Units –Total and Sensible Recovery with Humidity Control

Increased efficiency in cooling and dehumidification
The sensible device provides free reheat

- Heating options:
  hot water, steam, electric,
  indirect gas fired
- Cooling options:
  chilled water
  DX

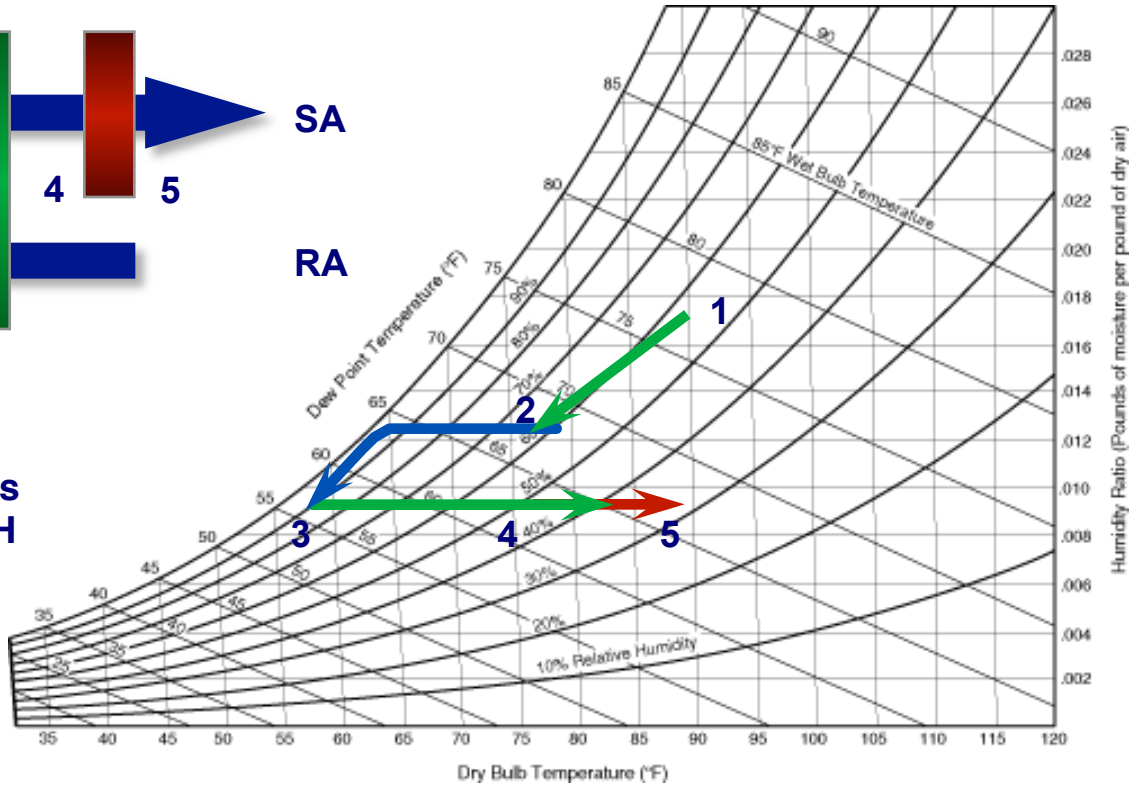


Total + Sensible Recovery



SUMMARY

Cooling Required: 22 Tons
Heating Required: 75 MBH



DOAS Component Config.

Item No.	Description of Equipment in the SA Flow Path	CC Load, Tons	SA DBT, °F	Lost Sensible Cooling Refrigerant CC Alone, Tons	Total Cooling Plant Input, DOAS Plus Lost Terminal Cooling	Author Ranking
1	CC	9.7	44	0.0	9.7	6
2	CC w/ HGRH	9.7	44-70	0.0	9.7	7
3	EW + CC	5.2	44	0.0	5.2	1
4	EW + PCC+CC+RHC	3.7	61.4	1.6	5.3	1
5	EW+CC+SW	4	68	2.2	6.2	5
6	PDHC+CC	9.7	53.1	0.8	10.5	8
7	EW+CC+PDHC	4	63.3	1.7	5.7	1
8	EW+PDHC+CC+PDHC	5.2	53	0.8	6.0	4
9	CC+ADesW	6.8	88.5	4	10.8	9

Table Abbreviation Key

CC	Cooling Coil	RHC	Reheat Coil (the downstream part of a CC runaround system)
HGRH	Hot Gas Reheat, or tempering	SW	Sensible Wheel
EW	Enthalpy Wheel	PDHC	Passive Dehumidification Component
PCC	Precooling Coil (the upstream part of a CC runaround system)	ADesW	Active Desiccant Wheel

Table 1: Summary comparison of the major DOAS equipment on the market today when conditioning 1,000 scfm of OA at 85°F and 148 gr/lbm$_{DA}$

DOAS Enthalpy Wheel Control

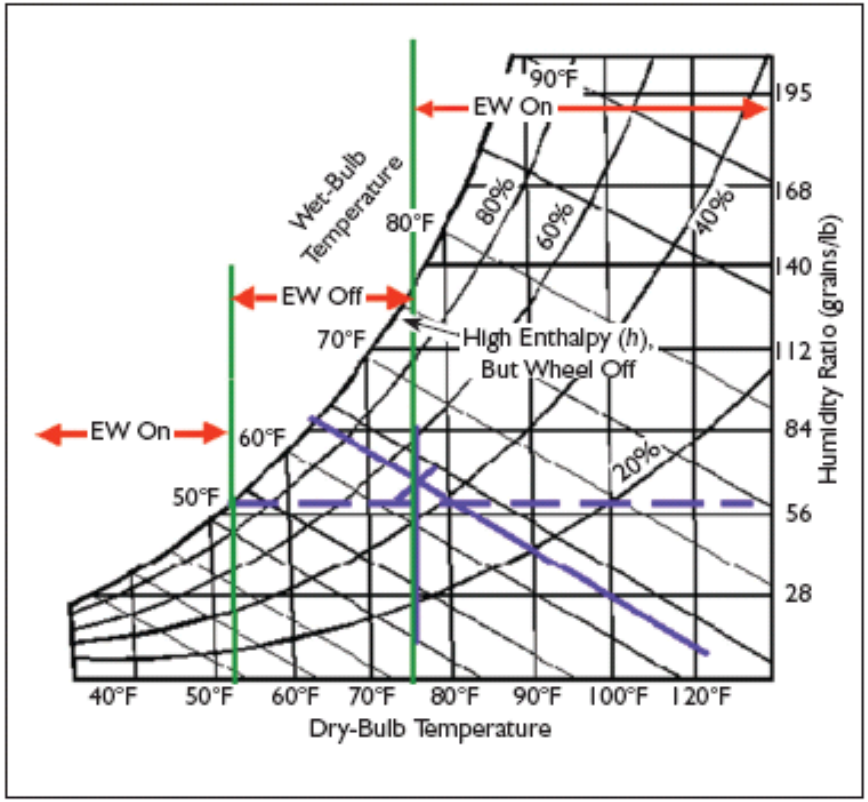


Figure 1: Incorrect enthalpy wheel control.

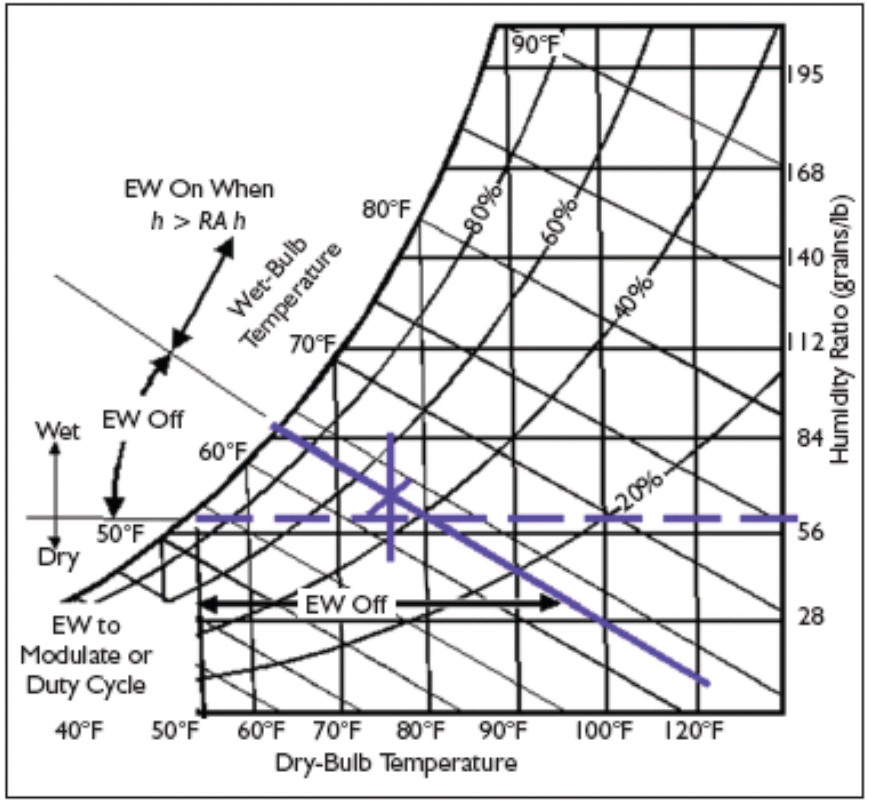
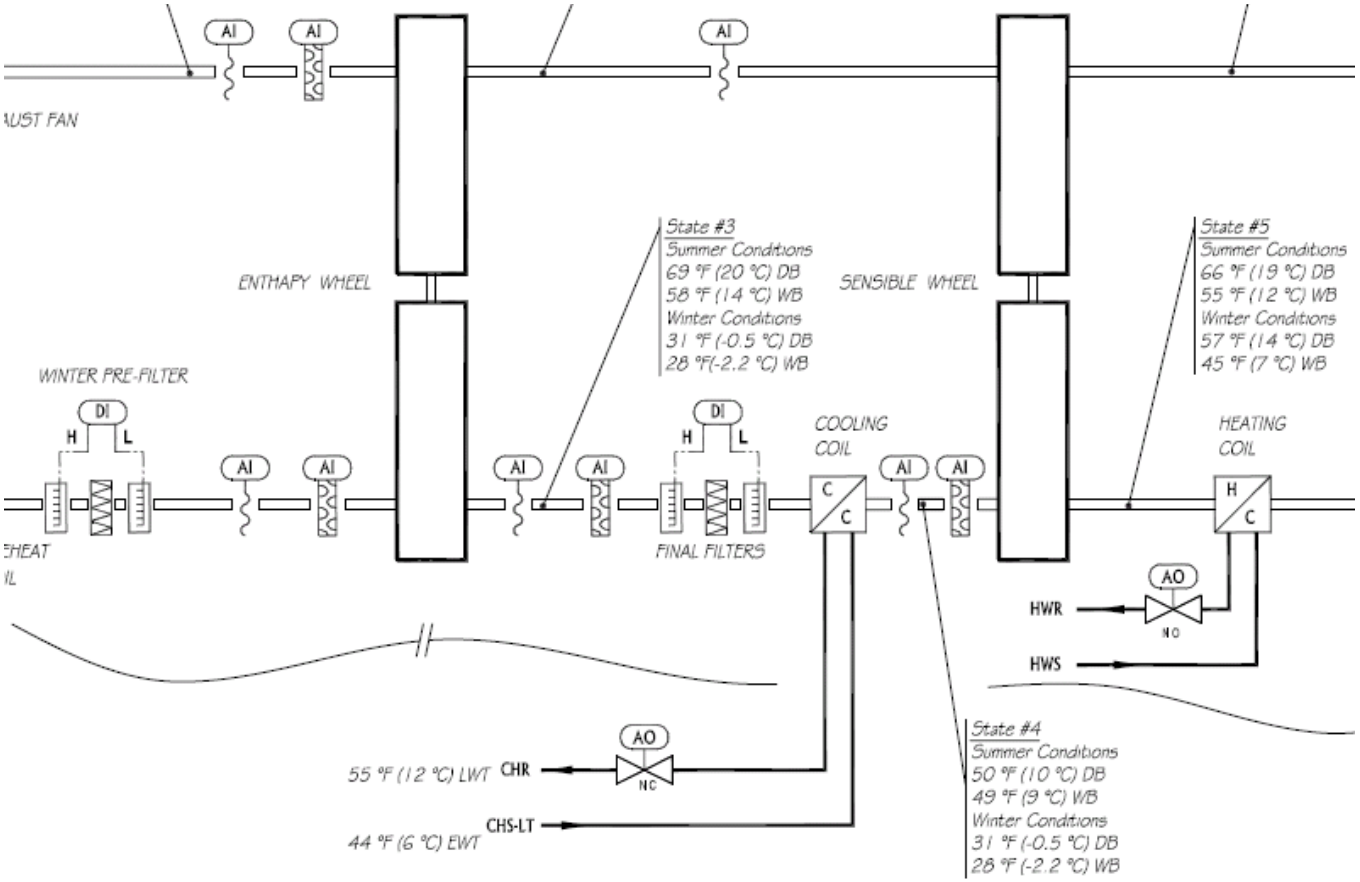


Figure 2: Recommended enthalpy wheel control.

DOAS Control Schematic

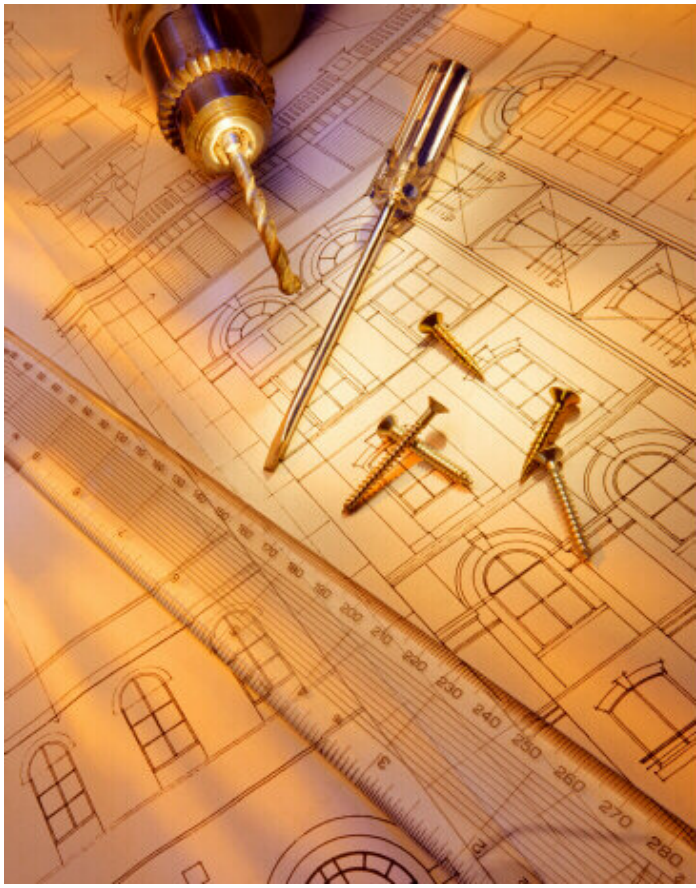


CO_2-Based DCV

- How does CO_2-based DCV work?
  - Start with Ci = Co + G/Vo
  - Tests show 80% of visitors are OK with human bioeffluent odors at outdoor airflow Vo = 15 cfm/p
  - Sedentary people generate CO_2 at 0.0105 cfm/p
  - If Co = 300 ppm, Ci = 300 + 10500/15 = 1000 ppm
  - So, Ci - Co = 700 ppm corresponds to 15 cfm/p in offices

Energy Efficient AHU Design

- Properly selected heat exchanger
- Proper design and selection of components
  - Efficient fan selections
  - Variable speed motors
  - Proper filtration stages
- Cabinet construction
  - Double wall center partition
  - Low leakage rates



Total Energy Savings

DOAS using variable speed:

1) Supply / Exhaust Fans
2) Air-Cooled Condenser Fans
3) Enthalpy Wheels
4) Compressors



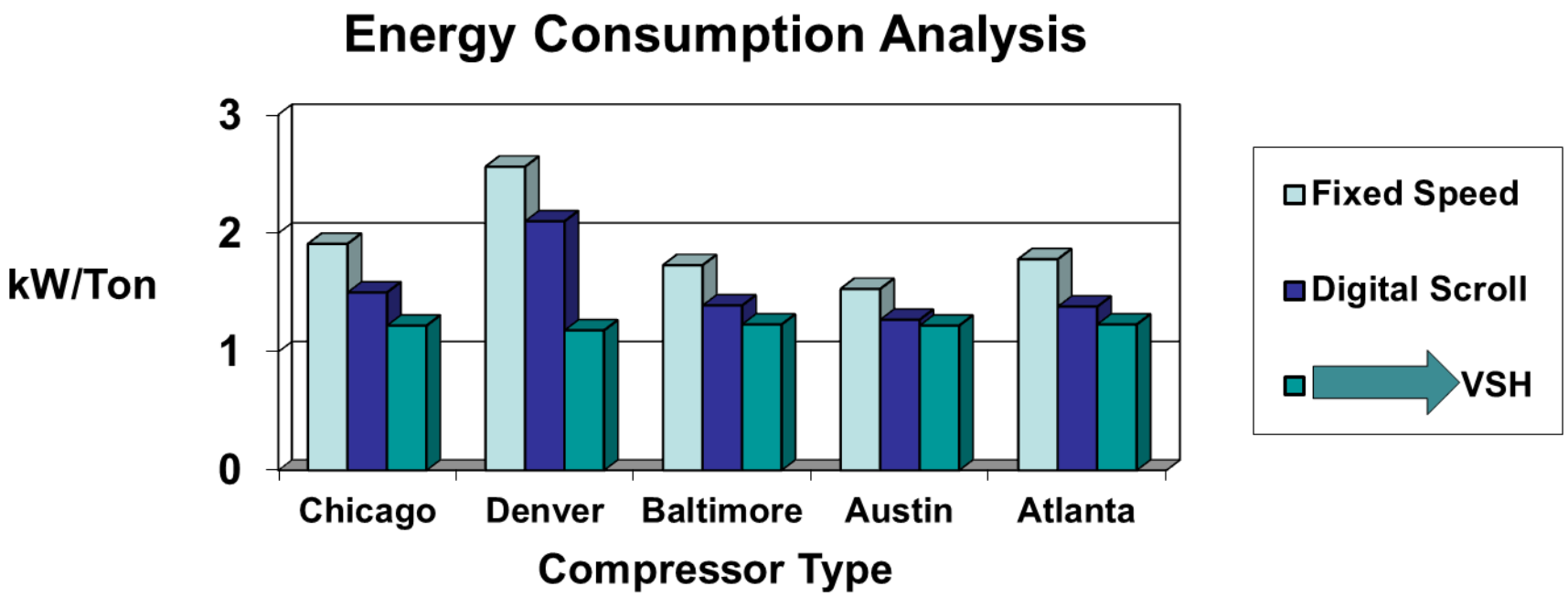


Variable speed compressors

- **Typical** Capacity range from 50-150%
- Environmentally-friendly R410a refrigerant
- Control to set point
- Elimination of hot gas bypass
- High part load EER
- Low inrush current
- Internal oil management system



Energy Savings



ASHRAE's BEST

FIRST PLACE: HEALTH CARE FACILITIES, EXISTING



Heating pumps equipped with variable frequency drives that modulate motor speed and water flow depending on load.

HOSPITAL RETROFIT

By Gilles Desmarais, eng., Member ASHRAE



Pierre-Boucher Hospital reduced annual energy bills by $210,000.

In addition, they also considerably trim down heating and cooling demands, allowing designers to downsize equipment capacity. To enhance heat exchange, wheel selections should be made to limit air velocity at 600 fpm (3.05 m/s). To prevent frost from forming on the wheels, glycol preheating coils should be installed. Enthalpy wheels are programmed to work when outdoor temperatures drop below 50°F (10°C) or rise above 77°F (25°C). Between 50°F and 77°F, (10°C to 25°C) enthalpy wheels are no longer profitable, since they can increase cooling energy to a point that will exceed heating and humidity savings.



Enthalpy wheels recover latent and sensible heat.

Building at a Glance

Name: Pierre-Boucher Hospital

Location: Longueuil, QC, Canada

Owner: CSSS Pierre-Boucher

Principal Use: Hospital services (340 beds)

Includes: emergency, intensive care, operating rooms, laboratories, nuclear medicine, medical imaging, oncology, sterilization, medical pharmacy, patient rooms, food services and external clinics.

Gross Square Footage: 500,000 ft^2

Substantial Completion/Occupancy: 2006

HVAC Energy Solution for LEED® Certification



LEED-NC (v2.2) EA Credit 1

Chiller Plant Efficiency: Series Counter-Flow

- Compare ASHRAE 90.1-2004 “Baseline” Building vs. “Proposed” Building with 2-Series Counter-Flow Chillers
- **Cooling Tower Optimization**
- Correct design WB, flow and temperature makes a difference
- **Series Counter-Flow + DOAS + Chilled Beam**
- Increase LEED Points

800 ton Commercial Office Building with Data Center



Project Data: (Baseline & Proposed)

Description	Baseline	Proposed
Design Model	Same as Proposed	ASHRAE 90.1-2004 Table G3.1
Space Usage Classification	“ “ “	“ “ “ “
Building Envelop and Schedules	“ “ “	“ “ “ “
Ventilation	“ “ “	ASHRAE 62.1-2004
Lighting	“ “ “	ASHRAE 90.1-2004 Table G3.1
Thermal Blocks	“ “ “	“ “ “ “
HVAC Systems	VAV, CW/HW per ASHAE 90.1-2004 G3.1.1 through G3.1.3	23XRV Series Counter-Flow, DOAS, Active Chilled Beams
Service Hot Water	Same as Proposed	ASHAE 90.1-2004 Section 7.4.2
Receptacle and Plug Loads	25% of Total Building Energy Cost	25% of Total Building Energy Cost

Dedicated Outdoor Air System

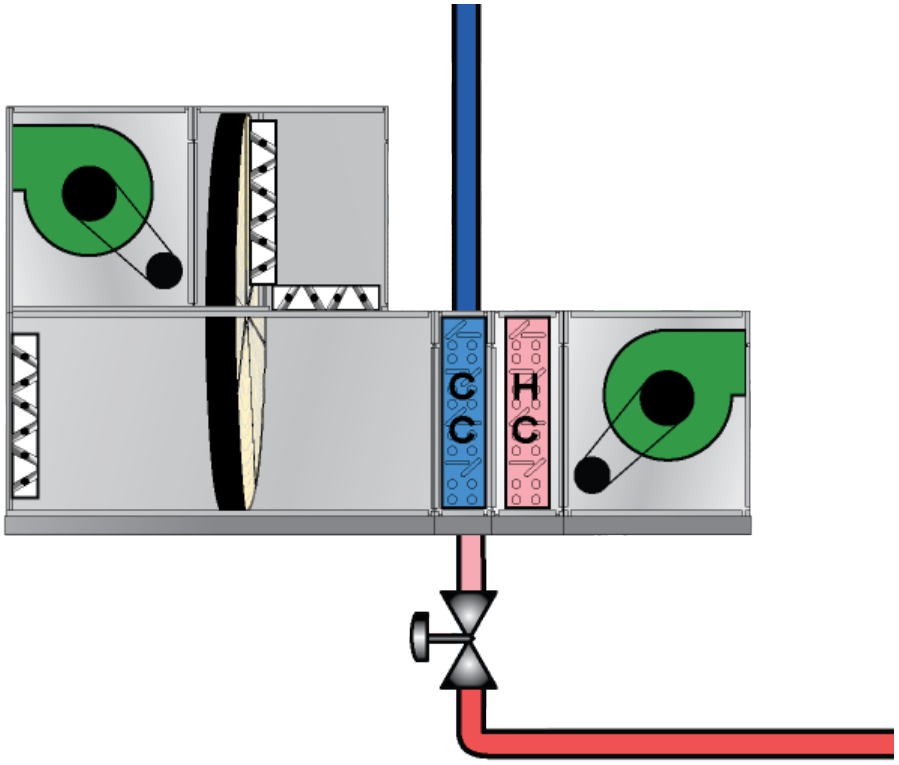
100% Outside Air

50% Effective ERV

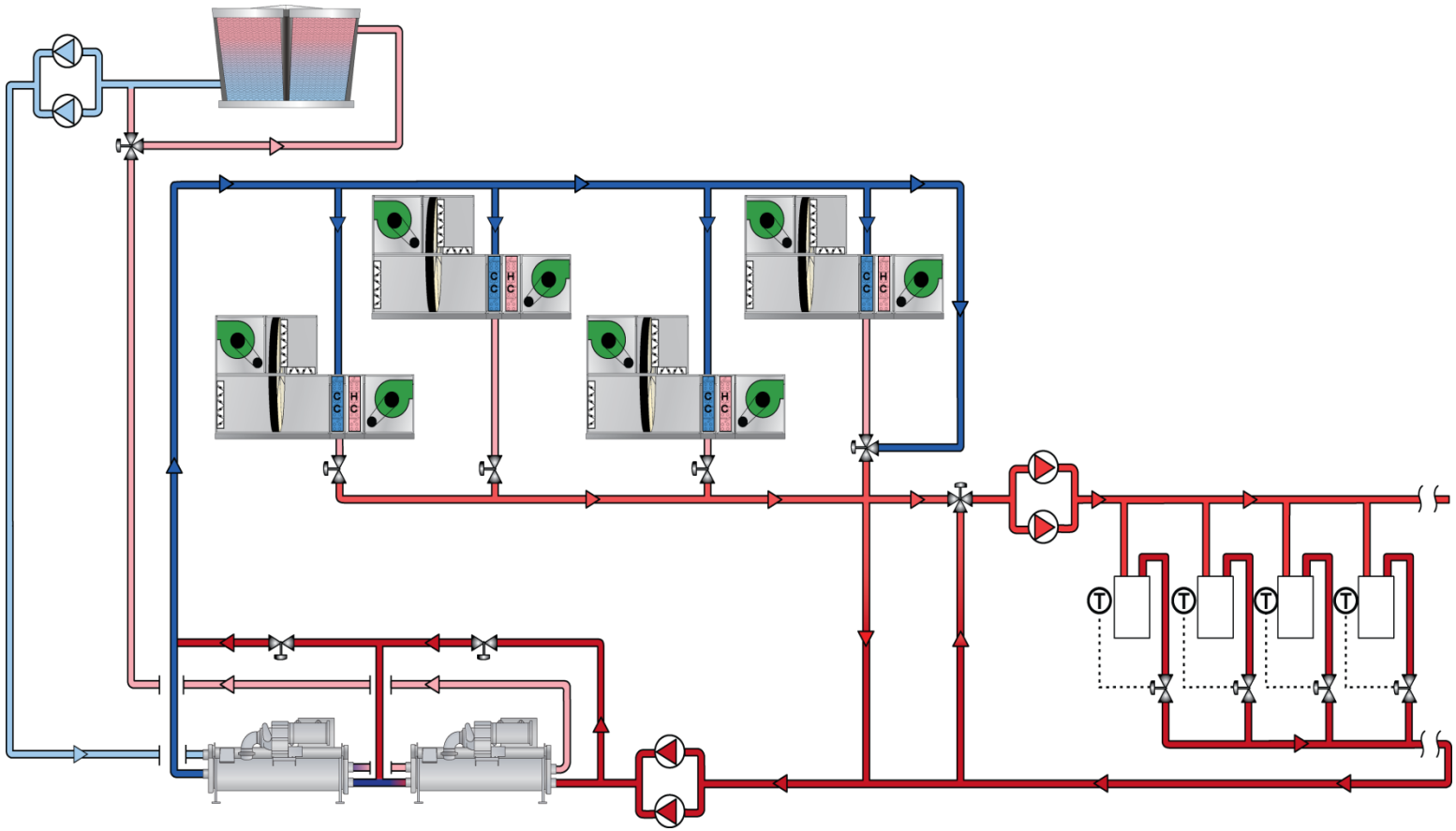
Chilled Water Coil, 44/54°F

Fan Hp per ASHRAE 90.1-2004

Filtration per ASHRAE 62.1-2007

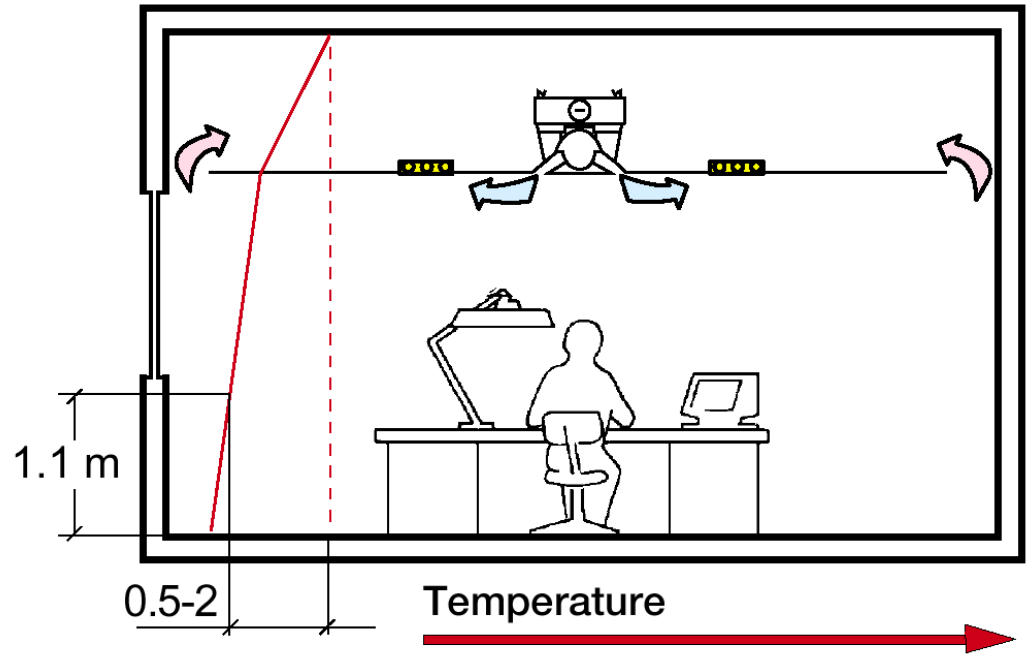


Series Counter-Flow Chiller Plant with 23XVR Chillers
Primary Variable Speed Loop, Secondary Active Chilled Beam Loop
44/60°F with reset
Chilled water pump sized for 100ft head



Active Chilled Beam

Induction air current mixes room air with ventilation air.



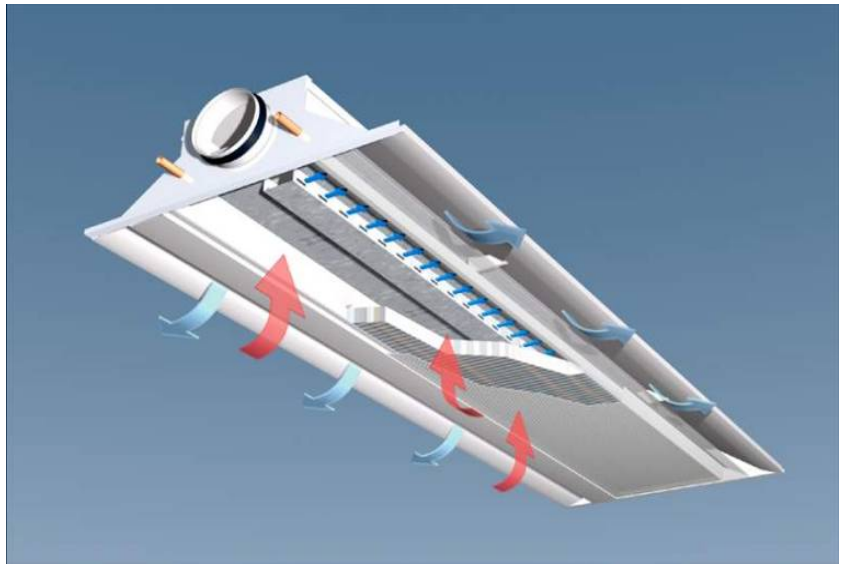


Fig. 4.2. An actual system with large convection sources.

Hourly Analysis Program (HAP)

Annual Cost Summary

23XRM LEED NC2.2 EAc1 Green Done Easy July 08 — 07/09/2008
Carrier — 08:49AM

Table 1. Annual Costs

Component	Base Building Design ($)	Proposed Building Design ($)
Air System Fans	235,914	59,846
Cooling	128,664	60,087
Heating	37,494	19,160
Pumps	88,421	55,208
Cooling Tower Fans	11,231	14,383
HVAC Sub-Total	**501,724**	**208,683**
Lights	195,537	189,499
Electric Equipment	156,436	151,605
Misc. Electric	3,835	3,716
Misc. Fuel Use	2,844	2,968
Non-HVAC Sub-Total	**358,651**	**347,787**
Grand Total	**860,374**	**556,471**

Percent Improvement

Performance Rating Method Compliance Report

Calculates % Energy Improvement

for LEED-NC v2.2, EAc1 Submittal Template - Table 1.8.2 - Performance Rating Table - Performance Rating Method Compliance

End Use	Energy Type	Proposed Building Energy Use [10^6 Btu]	Proposed Building Energy Use [kW-hr]	Proposed Building Energy Use [Therms]	Proposed Building Cost [$/yr]	Baseline Building Energy Use [10^6 Btu]	Baseline Building Energy Use [kW-hr]	Baseline Building Energy Use [Therms]	Proposed Building Energy Savings [%]
Interior Lighting (Ambient)	Electricity	5,171.7	1,515.3		$189,499	5,171.7	1,515.3		0.0%
Interior Lighting (Process)	Electricity		0.0			0.0	0.0		
Exterior Lighting	Electricity	49.3	14.4		$1,803	49.3	14.4		0.0%
Space Heating (fuel 1)	Natural Gas	2,368.7		23,686.6	$19,160	4,637.9		11,594.8	48.9%
Space Heating (fuel 2)	Electricity		0.0			0.0	0.0		
Space Cooling (fuel 1)	Electricity	1,529.4	448.1		$60,087	3,208.2	940.0		52.3%
Space Cooling (fuel 2)	Natural Gas			0.0		0.0		0.0	
Pumps	Electricity	1,498.2	439.0		$55,208	2,295.8	672.7		34.7%
Heat Rejection	Electricity	373.7	109.5		$14,383	277.8	81.4		-34.5%
Fans - Interior	Electricity	1,620.8	474.9		$59,846	6,193.4	1,814.6		73.8%
Fans - Parking Garage	Electricity		0.0			0.0	0.0		
Service Water Htg (fuel 1)	Natural Gas	348.6		3,486.5	$2,968	348.7		871.8	0.0%
Service Water Htg (fuel 2)	Electricity		0.0			0.0	0.0		
Receptacle Equipment	Electricity	4,137.5	1,212.3		$151,605	4,137.5	1,212.3		0.0%
Refrigeration (food, etc)	Electricity		0.0			0.0	0.0		
Cooking (commercial, fuel 1)	Natural Gas			0.0		0.0		0.0	
Cooking (commercial, fuel 2)	Electricity		0.0			0.0	0.0		
Elevators and Escalators	Electricity	52.1	15.3		$1,909	52.1	15.3		0.0%
Other Process	Electricity		0.0			0.0	0.0		
Total Building Consumption		**17,150**	**4,229**	**27,173.1**	**$556,468**	**26,372**	**6,266**	**12,466.5**	**35.32%**

Note: Energy Consumption is listed in terms of site energy

10^3 Btu = kWh X 3.413 10^3 Btu = therms / 100

Reference: LEED-NC 2.2 EAc1 Compliance Calculator (v8.1)

Determine LEED® Credit Points for Proposed Building

- EAc1 Points
- **% Savings = $\frac{\$\ 860{,}380 - \$556{,}468}{\$\ 860{,}380} = 35.32\ \%$**

8 points

New Construction or Major Renovation	*EA Credit Points*
10.5%	1
14.0%	2
17.5%	3
21.0%	4
24.5%	5
28.0%	6
31.5%	7
35.0%	8
38.5%	9
42.0%	10

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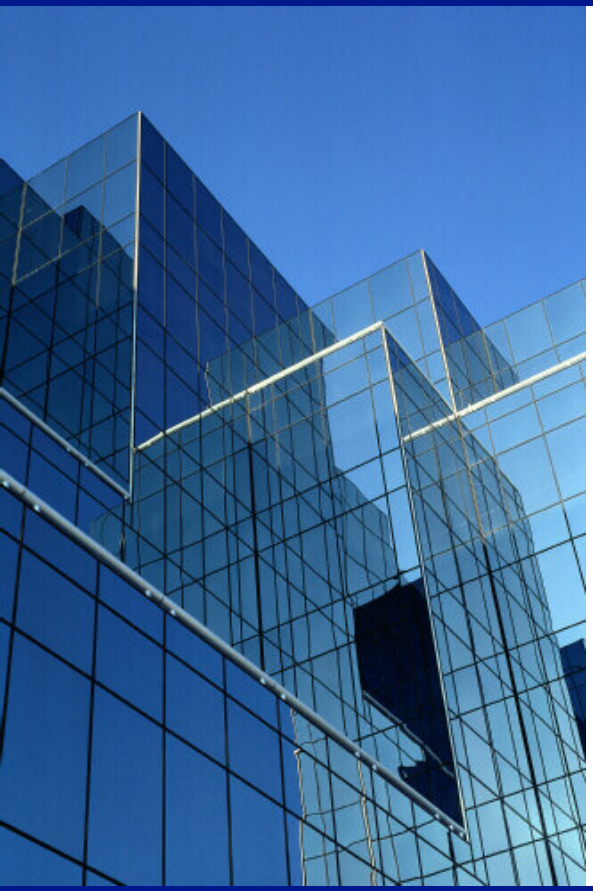

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